Volume 21 JANUARY, 1937 Number 1

BULLETIN
of the
American Association *of* Petroleum Geologists

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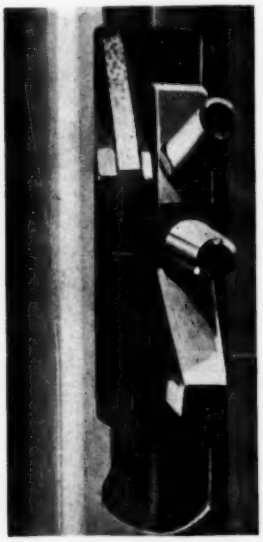

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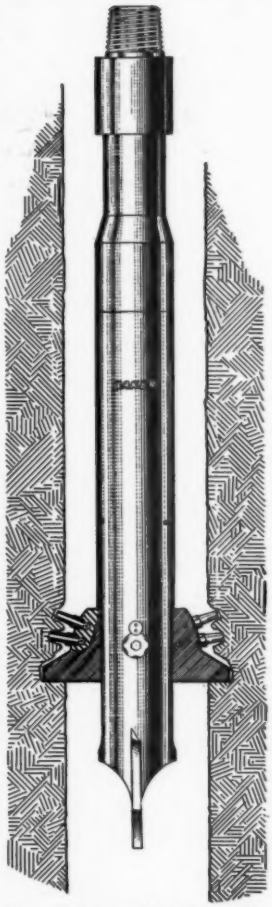

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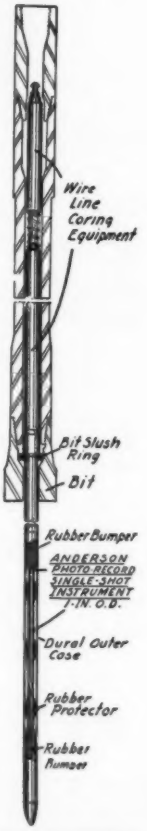

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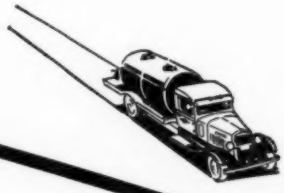

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Volume 21 Number 1

BULLETIN
of the
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JANUARY, 1937

GEOLOGY OF BLACK KNOB RIDGE, OKLAHOMA[1]

T. A. HENDRICKS, M. M. KNECHTEL, AND JOSIAH BRIDGE[2]
Washington, D. C.

ABSTRACT

Black Knob Ridge is situated at the west end of the Ouachita Mountains, near Atoka, and about 15 miles east of the east end of the Arbuckle Mountains. It is the westernmost area that reveals the facies of pre-Pennsylvanian rocks characteristic of the Ouachita Mountains. The strata in Black Knob Ridge dip eastward beneath the Pennsylvanian Stanley shale, which is overlain by the conformable sequence of the Jackfork sandstone, Johns Valley shale, and Atoka formation, all of which are of Pennsylvanian age. At the south end of Black Knob Ridge the Paleozoic strata are overlapped by beds of the Lower Cretaceous Trinity sand of the Gulf Coastal Plain, which dip gently southward. On the west side of Black Knob Ridge, south of Stringtown, the Caney shale, Springer formation, and Atoka formation of the facies or sequence characteristic of the Arbuckle Mountains are exposed. Northwest of Black Knob Ridge, north of Stringtown, undifferentiated shales and sandstones of Pennsylvanian age are exposed.

The rocks of Black Knob Ridge are composed of clastic siliceous sediments together with some siliceous limestones. They are almost identical in lithologic and faunal characteristics with rocks of the same age in the Potato Hills, Oklahoma, and are only slightly different from rocks of the same age in McCurtain County, Oklahoma, and the Arkansas part of the Ouachita Mountains. The rocks differ greatly in both lithologic character and fauna from rocks of the same time interval in the Arbuckle Mountains, but pronounced similarity between rocks at several horizons in Black Knob Ridge and rocks of equivalent age in the Arbuckle Mountains suggests that the basin of deposition of the rocks of Black Knob Ridge and the similar rocks farther east in the Ouachita Mountains was connected at least intermittently with the basin of deposition of the rocks characteristic of the Arbuckle Mountains. The greater abundance of limestone in the Bigfork chert in Black Knob Ridge than in the areas of its occurrence farther east suggests that the change from the Bigfork chert of the Ouachita Mountains to the Viola limestone of the Arbuckle Mountains was gradual within the basin of deposition; however, later northwestward thrusting of the rocks of Black Knob Ridge has moved them closer to the areas of deposition of the rocks of the Arbuckle Mountains and has therefore accentuated the two different sequences, one typically developed in the Arbuckle Mountains, and the other in the Ouachita Mountains.

Black Knob Ridge lies at the west side of the Oklahoma structural salient of the Ouachita Mountains and is made up of a series of rocks that dip steeply eastward and

[1] Published by permission of the director of the United States Geological Survey. Manuscript received, October 7, 1936.

[2] United States Geological Survey.

are bounded on the north and west by the Ti Valley and the combined Ti Valley and Choctaw faults. Along these faults the strata in Black Knob Ridge have been thrust northwestward 20 miles or more. The presence of several minor thrust faults and folds in Black Knob Ridge indicates that the movement along the Ti Valley fault was not entirely normal to the strike, but was in part parallel with the strike in a northerly direction. The overthrusting has moved the Black Knob Ridge rocks westward to within 15 miles of the Arbuckle Mountains over strata that, prior to the thrusting, were exposed in an uplift near the present position of Black Knob Ridge. The rocks in this uplift are similar to the sequence of the Arbuckle Mountains and are thus dissimilar to the overthrust rocks which belong to the sequence of the Ouachita Mountains.

INTRODUCTION

Black Knob Ridge is a low narrow ridge in western Atoka County, Oklahoma. It is formed by the outcropping edges of a series of formations that range in age from early Ordovician to Pennsylvanian. It is situated at the extreme western end of the Ouachita Mountains and is one of seven known areas of pre-Carboniferous rocks in the Oklahoma part of the Ouachita Mountains (Fig. 1).

In the fall of 1935, Knechtel and Hendricks mapped the geologic features of Black Knob Ridge in detail on an aerial photograph mosaic base on a scale of 2,000 feet to one inch, and together with Bridge and K. R. Parsons measured numerous stratigraphic sections and made fossil collections from all of the formations exposed there. This paper presents the results of that field work, together with the results of a study of the fossils by Bridge. The writers, under the guidance of H. D. Miser, also examined numerous sections of the formations exposed in the Potato Hills (Fig. 1) and the Arkansas part of the Ouachita Mountains for the purpose of comparing them with the formations of Black Knob Ridge.

STRATIGRAPHY

J. A. Taff,[3] in 1902, divided the pre-Pennsylvanian rocks of Black Knob Ridge into two formations, the Stringtown shale and the overlying Talihina chert, both of which he classified as Lower Silurian, which was then the age designation of strata now classified as Ordovician. Later, in the course of mapping in the Arkansas part of the Ouachita Mountains, Purdue and Miser subdivided the pre-Carboniferous rocks and applied several formation names to them. In connection with their work in Arkansas in 1908, Purdue, in company with E. O. Ulrich, J. A. Taff, and C. W. Hayes, visited the Potato Hills, Oklahoma, and recognized in the Talihina chert four units that had been named and mapped in Arkansas but not described or then pub-

[3] J. A. Taff, "Description of the Atoka Quadrangle," *U. S. Geol. Survey Atlas Folio 79* (1902).

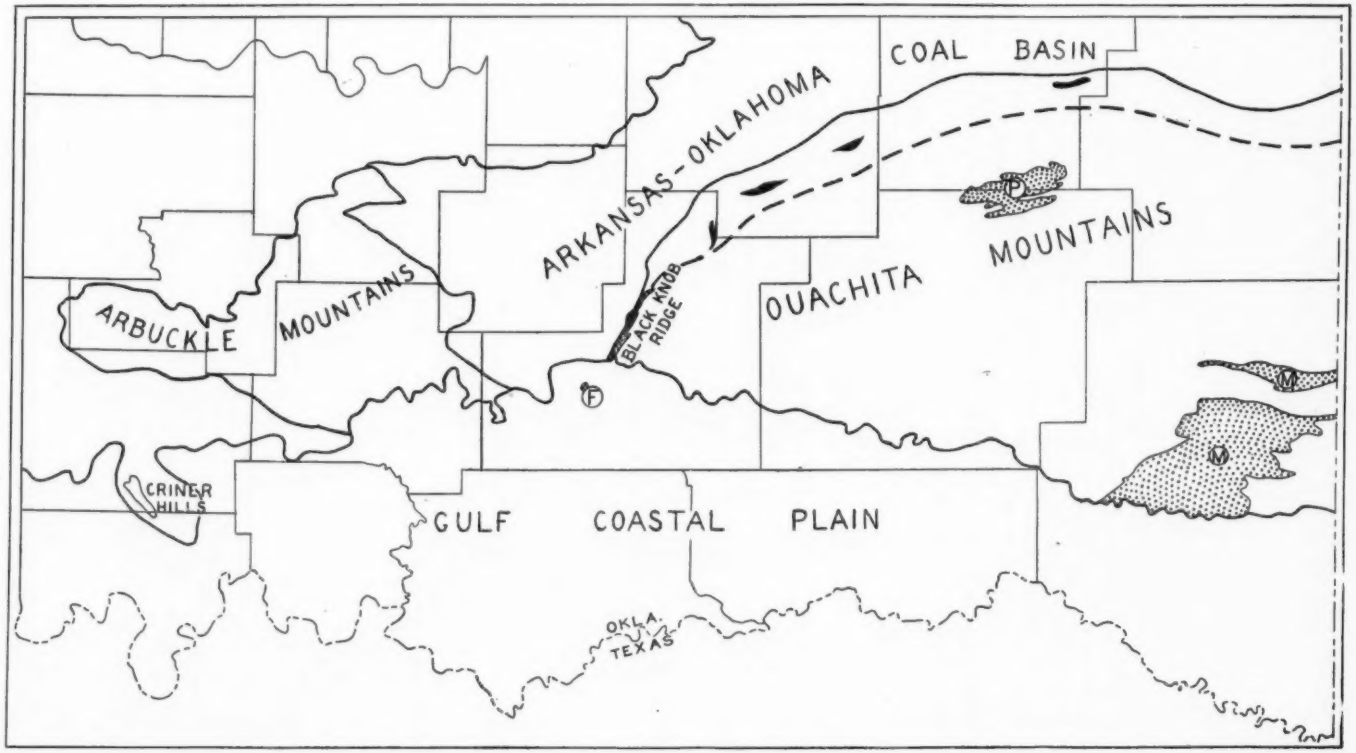

FIG. 1.—Outline map of southeastern Oklahoma showing geologic setting of Black Knob Ridge. Stippled areas represent occurrences of pre-Pennsylvanian rocks of facies characteristic of Ouachita Mountains; *P*, Potato Hills; *M*, McCurtain County; *F*, Frounterhouse Creek. Black areas represent exposures near north border of Ouachita Mountains of pre-Pennsylvanian rocks of facies characteristic of Arbuckle Mountains. Heavy broken line represents approximate southeastern boundary of area of occurrence of pre-Pennsylvanian rocks of facies typically developed in Arbuckle Mountains.

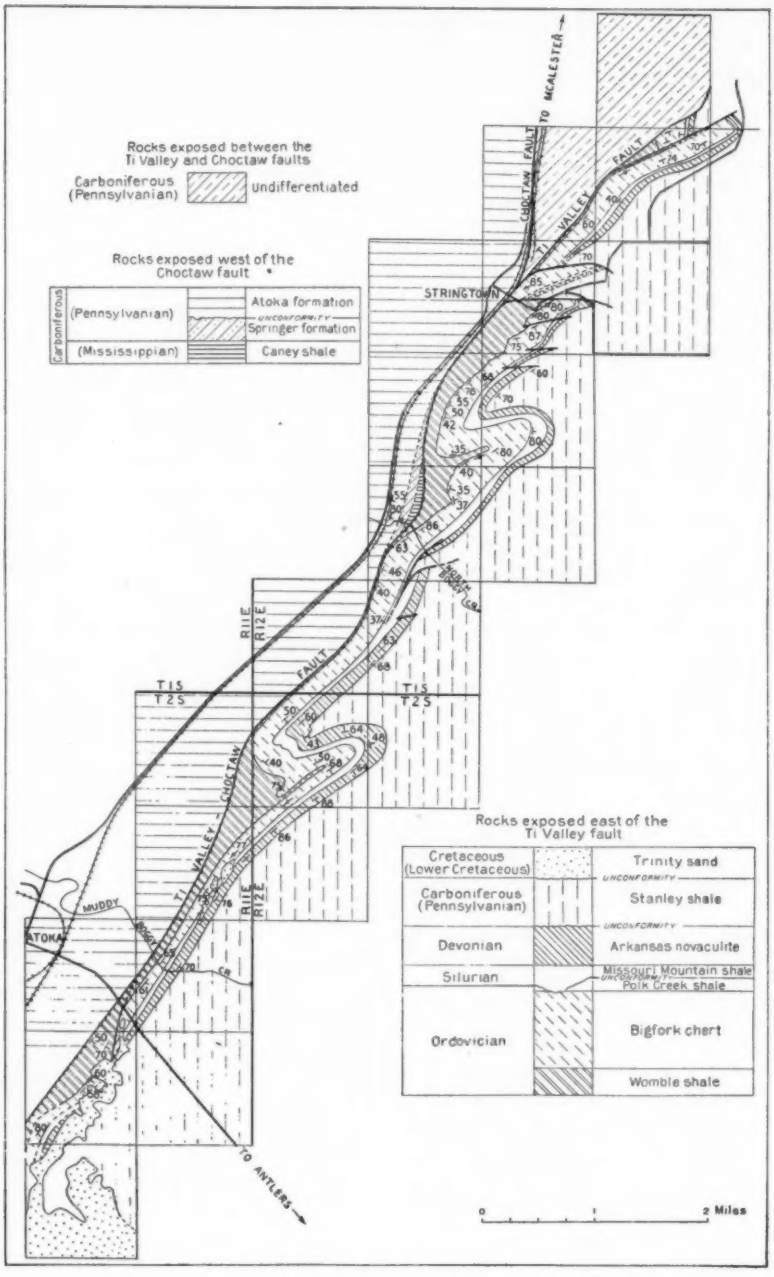

FIG. 2.—Areal geologic map of Black Knob Ridge and adjacent areas.

lished: the Bigfork chert, Polk Creek shale, Missouri Mountain shale, and Arkansas novaculite. In 1909, Purdue[4] described these and other formations, including the Stringtown, in a report on the slates of Arkansas.

The use of the name "Stringtown shale" in the Arkansas part of the Ouachita Mountains was discontinued in 1917 by Miser,[5] who introduced the name Womble shale, which includes strata in its upper part that are equivalent to Taff's Stringtown shale and which also includes some underlying beds not represented in the Stringtown shale at its type locality.

The formations recognized by Taff, Purdue, Ulrich, and Hayes in the Potato Hills, the type locality of the Talihina chert, were mapped by Miser in 1927. His mapping and classification of the formational units in the Potato Hills were published in a discussion of the structure of the Ouachita Mountains.[6]

In the course of the field work in Black Knob Ridge in 1935 the Womble shale, Bigfork chert, Polk Creek shale, Missouri Mountain shale, and Arkansas novaculite were mapped as formational units. The stratigraphic relationships of those formations, together with the overlying Stanley shale and overlapping Trinity formation, are shown by a diagrammatic columnar section on the geologic map (Fig. 2), on which are also shown diagrammatic columnar sections of the strata exposed adjacent to Black Knob Ridge west of the Choctaw fault and between the Ti Valley and Choctaw faults.

FORMATIONS EXPOSED EAST OF TI VALLEY FAULT

Womble shale.—The part of the Womble shale (Stringtown shale of Taff) exposed in Black Knob Ridge may be divided into two parts on the basis of lithologic character. The lower part consists of brown-to-green clay shale that weathers to a green clay and contains thin beds or lenses of soft sandstone made up of coarse, rounded, and frosted sand grains. That shale unit is at least 166 feet thick, but the base of all sections is a fault contact and the full thickness can not be determined. The upper part of the formation consists of brown-to-black shale 80–95 feet thick, much of which is cherty. It weathers to a light gray or almost white platy shale. Many of the beds in the upper part contain scattered coarse, well rounded, and frosted sand grains.

[4] A. H. Purdue, "The Slates of Arkansas," *Arkansas Geol. Survey* (1909), pp. 34–40.

[5] H. D. Miser, "Manganese Deposits of the Caddo Gap and DeQueen Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 660* (1917), p. 67.

[6] H. D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Oklahoma Geol. Survey Bull. 50* (1929), p. 19.

All parts of the formation are fossiliferous, the dominant fossils being graptolites with a few associated orbiculoidea, lingulae, conodonts, spines, and spicules. Both lithologically and faunally the part of the formation exposed in Black Knob Ridge is similar to the upper part of the Womble shale of the DeQueen and Caddo Gap quadrangles in Arkansas.[7]

Two zones of graptolites are represented, the lower one characterized by *Nemagraptus gracilis* (Hall), the upper by an abundance of *Dicranograptus nicholsoni* var. *parvangulus* Gurley. The brachiopod *Leptobolus walcotti* Ruedemann is abundant in certain layers in both zones. The upper zone is in the black shale which lies just beneath the Bigfork chert. Both faunas are found in the upper part of the Womble shale of Arkansas.[8] Both are characteristic of the Normanskill shale of New York and the Athens shale of the Appalachian Valley. The Normanskill and Athens shales are commonly classed as Chazy, but may actually be of Black River age.

Bigfork chert.—The Bigfork chert overlies the Womble shale with an apparently conformable contact, and in some exposures the contact appears to be gradational. The formation is consistently about 600 feet thick, and may be divided into two parts on the basis of lithology. The parts are not of member rank, because as one thickens the other thins, and the entire formation maintains a uniform thickness, thus indicating that the line of division between the two occurs at different stratigraphic positions in different sections. The lower part is 410–510 feet thick and is characterized by light gray-to-light brown chert in beds mostly 2–4 inches thick, although some are as thick as one foot. Gray limestone forms beds, stringers, and lenses in the chert and locally constitutes about one-fifth of the lower part of the formation. The limestone for the most part is finely crystalline, but a few thin beds in each well exposed section are coarsely crystalline. The upper part of the formation, 100–190 feet thick, consists of chert in beds ranging from one inch to 2 feet thick in which no limestone is present and in which beds of black paper shale as thick as 2 feet are intercalated. The chert in this zone is finely laminated parallel with the bedding and is very dark brown-to-drab.

At least four distinctly different types of chert are present in the Bigfork. In the lower part of the formation are many chert nodules flattened parallel with the bedding. The bedding and laminae of the overlying chert and limestone curve upward over the nodules but

[7] H. D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929), pp. 32–33.

[8] H. D. Miser and A. H. Purdue, *op. cit.*, pp. 33–35.

are thinner directly above than on the sides of each nodule, so that the upward curving of the beds decreases progressively away from the nodule and disappears completely within one foot or less. Most of the chert in the lower part of the formation, however, is composed of even-bedded layers whose thicknesses range from a small fraction of an inch to about one foot. The limestones are so siliceous that samples from which all the calcareous material has been leached retain their form and are made up of a spongy porous mass of silica. Locally the chert beds pass laterally into siliceous limestone. Generally where the lateral transition from chert to limestone occurs the contact between chert and limestone appears as a nearly straight line normal to the bedding and the limestone part of the bed is thicker than the chert part. Associated with the bedded chert of the lower part of the Bigfork are some lenticular chert masses in which the chert is arranged in more or less concentric light and dark gray bands. The banding of the lenticular chert cuts across the original bedding laminae, which show no tendency to conform with the shape of the nodule.

The presence of limestone bands and fossils which were originally calcareous indicates that the lower part of the formation was originally a limestone, but the abundance of spicules and radiolaria indicates that the limestone was highly siliceous. The color-banded chert nodules and the lateral transition from siliceous limestone to chert show that most of the chert as it is seen to-day is secondary; however, the abundance of siliceous organisms and the general decrease in thickness from siliceous limestone to chert at the points of lateral transition indicate that much, if not all, of the silica that has formed the chert was native to the formation and has been changed to beds of chert by solution of the original opaline silica and redeposition as the more stable chert. It seems probable that the internal rearrangement of silica occurred in large part soon after deposition and was a part of the process of compaction and lithifaction. The presence of calcite-filled fracture planes normal to the bedding suggests that the amount of siliceous material in the formation has been concentrated somewhat by the solution and removal of the easily soluble calcium carbonate of the limestone after the lithifaction of the rocks.

Neither limestone nor originally calcareous fossils have been found in the chert that alternates with black shale in the upper part of the formation, but siliceous spicules and radiolaria are present there. Those features suggest that the upper part of the formation was originally highly siliceous and that the chert has been formed at least in major part by a change from less stable forms of silica to the more stable chert, with little or no migration of material.

The fauna of the Bigfork is composed of graptolites, small brachiopods, trilobites, conodonts, spicules of various sorts, and small bodies which may be radiolarians. The graptolites occur at several horizons throughout the formation, and for the most part they are conspecific with those found in the Viola limestone of the Arbuckle region. They are of Trenton age and have recently been described by Ruedemann and Decker.[9] Collections made by the writers show that the Bigfork contains more Viola species than would appear from Decker's list.

All of the trilobites found to date belong to the genus *Cryptolithus*. They occur in several layers in the lower hundred feet of the Bigfork and seem to be conspecific with forms occurring in the lower part of the Viola. The other forms have not been studied.

Some of the species of graptolites found in the Bigfork of Black Knob Ridge are also found in the Bigfork of Arkansas and serve to confirm other evidence for the general equivalence of the sections in these two areas.

Polk Creek shale.—The Polk Creek shale overlies the Bigfork chert with an apparently conformable contact. The basal part of the Polk Creek shale consists of hard, black, paper shale that grades upward into soft, brown, platy shale marked by numerous small cavities in which soft, yellow, clayey pellets are present. The formation varies greatly in thickness in Black Knob Ridge, the maximum thickness being more than 139 feet in a section at the Atoka city trash dump in the SW. ¼ of Sec. 13, T. 2 S., R. 11 E., where the top of the formation is covered. About 70 feet of the formation is exposed in the channel of a small northward flowing stream in the E. ½, NE. ¼, SE. ¼ of Sec. 20, T. 1 S., R. 12 E., and, as in the preceding section, the upper part is covered. In a section exposed in the bed of a small, eastward flowing stream in the SW. ¼, SE. ¼, SW. ¼ of Sec. 21, T. 1 S., R. 12 E., which lies between the two sections previously mentioned, the Polk Creek shale is absent. Northeast of Stringtown it is absent in all exposures except one located in a small stream valley in the NW. ¼, SW. ¼ of Sec. 10, T. 1 S., R. 12 E., about ¼ mile west of Grant's Gap. In that stream bed 4 feet of brown graptolite-bearing shale containing chert nodules is present above the Bigfork chert.

The fossils of the Polk Creek shale of Black Knob Ridge consist primarily of graptolites. The species are identical with forms from the Polk Creek shale of Arkansas and the Sylvan shale of the Arbuckle Mountains. This fauna has recently been described by Decker[10] and

[9] Rudolf Ruedemann and Charles E. Decker, "The Graptolites of the Viola Limestone," *Jour. Paleon.*, Vol. 8, No. 3 (1934), pp. 303–27.

[10] Charles E. Decker, "Graptolites of the Sylvan Shale of Oklahoma and Polk Creek Shale of Arkansas," *Jour. Paleon.*, Vol. 9, No. 8 (1935), pp. 697–708.

most of the species listed by him have been found in the collections from Black Knob Ridge. The most common and easily identified form is *Dicellograptus complanatus* Lapworth, which occurs in all parts of the formation. *Climacograptus mississippiensis* Ruedemann is abundant in the lower third throughout the formation. *Climacograptus ulrichi* Ruedemann and *C. putillus* (Hall) are abundant in the upper two-thirds. These last two species also occur in the Maquoketa shale of Missouri. On the basis of these graptolites the Polk Creek shale of Black Knob Ridge is correlated with a part of the Maquoketa shale and is considered to be of Richmond age.

Missouri Mountain shale.—The Missouri Mountain shale overlies the Polk Creek shale with an unconformable contact. In all exposures northeast of Stringtown except the one already described, about ¼ mile west of Grant's Gap, the Polk Creek shale is absent beneath the unconformity and the Missouri Mountain shale rests unconformably on the Bigfork chert. The formation is about 110 feet thick and consists chiefly of hard, green, gritty and siliceous shale in which are thin beds of finely laminated chert, and local lenses of hard conglomerate. In a section exposed in Grant's Gap, SE. ¼, SW. ¼ of Sec. 10, T. 1 S., R. 12 E., 3 feet of green shale containing chert fragments and sand grains lies at the base of the formation. Locally, some of the shale of the formation is of the variegated red and green type, and in all exposures dendritic manganese stains are common in the shale.

The local conglomerate lenses occur at several horizons in the Missouri Mountain shale. They contain coarse grains and pebbles, as large as an inch in diameter, interbedded in a vitreous siliceous matrix. The fragments in the conglomerate include hard green shale of the type common in the Missouri Mountain shale itself, hard black shale of the type common in the basal part of the Polk Creek shale and the upper part of the Bigfork chert, and chert similar to that present in the Bigfork chert. It is the writers' opinion that the conglomerates represent minor unconformities or diastems and indicate that beds at least as old as the Bigfork chert were undergoing erosion near the points of deposition of the conglomerates at several stages during the deposition of the Missouri Mountain shale. The general northward disappearance of the Polk Creek shale in Black Knob Ridge suggests that the areas undergoing erosion lay north of the basin of deposition of the Missouri Mountain shale and that the Missouri Mountain shale now found in Black Knob Ridge was deposited near the north margin of the basin of deposition of the formation as a whole.

Two collections of fossils were made from the upper part of the

Missouri Mountain shale in Grant's Gap, in the SE. ¼, SW. ¼ of Sec. 10, T. 1 S., R. 12 E. A few conodonts, spicules, and fragments of brachiopods together with one bryozoan were found. They appear to be of Silurian age, and therefore to support the conclusions reached by Miser and Purdue[11] on the basis of the stratigraphic relations and lithologic character of the formation.

Arkansas novaculite.—The Arkansas novaculite overlies the Missouri Mountain shale throughout Black Knob Ridge. The contact between the two formations appears to be gradational in the few places where it is exposed. The Arkansas novaculite varies from 234 to 340 feet in thickness in sections measured in Black Knob Ridge and is made up of four lithologic members. The lowest member constitutes about half of the formation and is made up of thin-bedded, light-colored novaculite, much of which is apple-green in color, interbedded with hard green shale. The second lithologic member constitutes about half of the upper part of the formation and is made up of beds of novaculite of variable thickness that are light gray-to-almost black and are separated by thin partings and beds of black paper shale. The two uppermost members are about equal in thickness and together constitute about one-fourth of the formation. The lower of these two members consists of red and green, gritty, micaceous, and flaky shale that weathers to a soft clay and contains some thin beds of novaculite, particularly in the lower part, and some local beds of blocky black shale. The upper member consists of green, brown, and gray novaculite in beds ranging from one inch to one foot thick.

L. G. Henbest[12] has studied thin sections of novaculite from the Potato Hills, Oklahoma, in which he found abundant radiolaria. The discovery of abundant radiolaria in the novaculite indicates that the beds contained some silica originally and led Henbest to suggest the "absence of any extensive surficial replacement of original limestone beds." That suggestion is in agreement with the conclusions of Miser and Purdue[13] regarding the original character of the novaculite in the DeQueen and Caddo Gap quadrangles, Arkansas. Their conclusions were based on the mechanical difficulty of accomplishing such uniformly perfect replacement over the entire area of occurrence of the novaculite as would have been necessary if the novaculite had replaced originally non-siliceous beds. C. W. Honess[14] noted abundant volcanic

[11] H. D. Miser and A. H. Purdue, *op. cit.*, pp. 48–49.

[12] L. G. Henbest, "Radiolaria in the Arkansas Novaculite, Caballos Novaculite, and Bigfork Chert," *Jour. Paleon.*, Vol. 10, No. 1 (January, 1936), pp. 76–78.

[13] H. D. Miser and A. H. Purdue, *op. cit.*, p. 57.

[14] C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Oklahoma Geol. Survey Bull. 32* (1923), pp. 121–39.

material in thin sections of novaculite from the lower part of the formation in McCurtain County, Oklahoma, but concluded largely from the uniformly high silica content and the lithologic character that the novaculite was initially siliceous and was formed by chemical precipitation of silica.

A number of thin sections of the novaculite from Black Knob Ridge have been examined and radiolaria are present in sections of the novaculite collected from the upper part of the formation. As in the other areas where the novaculite has been studied, the uniformly high silica content and the absence of any remnants of carbonate material other than clearly secondary crystals similar to those described by Honess[15] leads to the conclusion that the novaculite is an initially siliceous deposit and not a replacement of limestone or other material. The presence of radiolaria indicates that the silica was derived at least in part from siliceous organisms.

No fossils were found in the lower half of the novaculite, but in the upper half abundant conodonts, radiolaria, and spores together with some silicified wood and lingulae are present. The conodonts collected from the upper part of the novaculite in Black Knob Ridge constitute a Chattanooga shale fauna similar to that described by C. L. Cooper[16] from the middle and upper parts of the Arkansas novaculite at Caddo Gap, Arkansas. According to the age classification of the Chattanooga shale in parts of Oklahoma and Arkansas by the United States Geological Survey, the fossils studied place the upper part of the Arkansas novaculite in the Upper Devonian(?). Miser and Purdue[17] classified the lower part of the Arkansas novaculite in the De-Queen and Caddo Gap quadrangles as Middle Devonian on the basis of lithologic similarity to the Middle Devonian Pinetop chert exposed near Ti in the northern part of the Ouachita Mountains and also to the Middle Devonian Camden chert of Tennessee. That lithologic similarity continues into the Black Knob Ridge area, and, in the absence of data to the contrary, the lower part of the Arkansas novaculite is considered Middle Devonian in age.

Stanley shale.—The Stanley shale overlies the Arkansas novaculite unconformably in Black Knob Ridge. The contact between the two formations appears to be gradational in most exposures, but it is the writers' opinion that the upward gradation from the novaculite

[15] C. W. Honess, *op. cit.*, p. 132.

[16] C. L. Cooper, "Conodonts from the Upper and Middle Arkansas Novaculite, Mississippian, at Caddo Gap, Arkansas," *Jour. Paleon.*, Vol. 9, No. 4 (June, 1935), pp. 307–15.

[17] H. D. Miser and A. H. Purdue, *op. cit.*, pp. 58–59.

to the Stanley shale is due to the presence in the basal beds of the Stanley shale of an abundance of mechanically and chemically reworked siliceous material from the novaculite. The basal beds of the Stanley shale are hard green-to-buff siltstones and shales. Some of the siltstones are cherty and are characterized by a siliceous cement. Above its basal part the Stanley shale consists of gray clay shale that weathers greenish gray alternating with beds of siltstone as thick as 100 feet. At several horizons in the formation, beds of siliceous shale ranging from blue-gray to black in color and from 15 to 75 feet in thickness are present, and a bed of variegated red and green clay shale about 15 feet thick is present in the upper part of the formation. Cone-in-cone structure is common in concretions and in thin layers that are abundant at many horizons in the formation. The thickness of the Stanley shale can not be determined near Black Knob Ridge, because all outcrops of the formation are broken by thrust faults of unknown stratigraphic displacement.

The shales and siltstones contain abundant fragmental plant material, and the siliceous shales contain spores and many conodonts and spicules. The fossils collected by the writers have not been studied, and no contribution to the determination of the age of the formation can be made here. According to David White[18] who studied plants collected from the upper part of the Stanley shale, the formation is of Lower Pennsylvanian (Pottsville) age. B. H. Harlton,[19] who has studied invertebrates collected from the Stanley shale, also places it in the lower part of the Pennsylvanian.

Overlying the Stanley shale east of Black Knob Ridge is a conformable sequence of many thousands of feet of clastic sediments of Lower Pennsylvanian (Pottsville) age that has been divided into three formations on lithologic character. Those formations are, in ascending order, the Jackfork sandstone, Johns Valley shale, and Atoka formation.

Trinity sand.—At the south end of Black Knob Ridge, both the Pennsylvanian and older rocks pass beneath overlapping strata of the Trinity sand of Lower Cretaceous age. The basal part of the Trinity sand is a coarse conglomerate about 10 feet thick made up of well rounded pebbles of quartz, quartzite, chert, sandstone, and novaculite in a matrix of sand. Locally, the conglomerate is cemented with silica and is so hard that it breaks across rather than around the sili-

[18] David White, "Age of Jackfork and Stanley Formations of Ouachita Geosyncline, Arkansas and Oklahoma, as Indicated by Plants," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), pp. 1010–17.

[19] B. H. Harlton, "Carboniferous Stratigraphy of the Ouachitas with Special Study of the Bendian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), p. 1020.

ceous pebbles. At other places the conglomerate is soft and poorly cemented. Overlying the conglomerate are soft sand and sandy shale. Several outliers of the basal conglomerate are present on the crest of Black Knob Ridge at least 2 miles north of the border of the Coastal Plain, and residual boulders of the conglomerate that are present near the north end of Black Knob Ridge indicate that beds of Trinity age once covered the entire area and have been removed by erosion.

FORMATIONS EXPOSED WEST OF CHOCTAW FAULT

West of the Choctaw fault and adjacent to Black Knob Ridge there is exposed a sequence of Mississippian and Pennsylvanian strata entirely different from the sequence of strata exposed in and east of Black Knob Ridge. The formations exposed there are, in ascending order, the Caney shale, Springer formation, and Atoka formation.

Caney shale.—At one locality immediately west of the Choctaw fault and adjacent to Black Knob Ridge, Caney shale is exposed. The exposure is located in the SE. cor. of the NW. ¼ of Sec. 29, T. 1 S., R. 12 E., and lies about 100 feet north of North Boggy Creek in the bed of a small tributary stream. The exposure of Caney shale consists of about 20 feet of badly crumpled and slickensided black clay shale in which are imbedded large septarian concretions and small phosphatic nodules. Some fragments of plant material and a single brachiopod were collected from the Caney shale at that locality. The brachiopod was identified as *Leiorhynchus carboniferum* Girty by J. S. Williams, who states that according to present knowledge that species is Mississippian.[20]

Springer formation.—The Springer formation overlies the Caney shale conformably in the exposure on the north side of North Boggy Creek in the SE. ¼, NW. ¼ of Sec. 29, T. 1 S., R. 12 E., and continues westward for about 400 feet to the north abutment of an abandoned railroad bridge across North Boggy Creek. The exposed strata consist of badly crumpled and slickensided black shale that contains septarian concretions and small phosphatic nodules. It can not be distinguished from the underlying Caney shale on the basis of lithology, but several specimens of a cephalopod collected from a septarian concretion in the base of the exposed part of the formation indicate Pennsylvanian age. The cephalopods were studied by J. S. Williams, who states,

> I believe most of the pieces of cephalopods probably belong to *Gastrioceras* and are close to but not identical with the larger form identified by Mather as *Gastrioceras branneri* Smith from the Morrow. The species represented is also close to undescribed Morrow species in our collections. It does not closely

[20] Memorandum dated March 12, 1936.

represent any of our Mississippian Caney shale species . . . . As *Gastrioceras* is generally interpreted in this country, most, if not all of the species are Pennsylvanian or younger.[21]

Atoka formation.—The writers have not as yet studied in detail the Atoko formation immediately west of the Choctaw fault, but several features that have an important bearing on the geology of Black Knob Ridge have been observed. The base of the Atoka formation has been observed at only one place, the exposure at the north abutment of the abandoned railway bridge across North Boggy Creek in the NW. ¼ of Sec. 29, T. 1 S., R. 12 E. At that place the Atoka formation rests unconformably on beds of the Springer formation, but because of the reworking of material from the Springer formation the contact appears to be gradational. In adjacent areas farther north and west, the Wapanucka limestone is present between the Springer and Atoka formations, but at this locality it has been overlapped by the Atoka strata. The Atoka formation consists of several thousand feet of gray-to-brown, sandy, micaceous shale alternating with beds of conglomerate and sandstone. The pebbles in the conglomerates are mostly chert and range in size from granules to pebbles 3 inches in diameter. A single phosphatic nodule of the type common in the Springer formation and Caney shale was found in a bed of conglomerate in the lower part of the Atoka formation exposed in a railroad cut in the NE. ¼ of Sec. 22, T. 2 S., R. 11 E. The discovery of that pebble seems to substantiate the evidence of an unconformity at the base of the Atoka formation west of Black Knob Ridge.

No evidence was obtained by the writers as to the age of the Atoka formation, but David White[22] stated that the Atoka formation, on the basis of plant fossils collected near Atoka, Oklahoma, is upper Pottsville.

ROCKS EXPOSED BETWEEN CHOCTAW AND TI VALLEY FAULTS

A series of alternating sandstone and shale beds is exposed between the Choctaw and Ti Valley faults immediately northwest of Black Knob Ridge. Those beds are shown on the Oklahoma State geologic map[23] as a part of the Atoka formation. However, some of the outcrops observed by the writers in that area are identical in lithologic character with beds in the Stanley and Jackfork formations and are unlike any beds known definitely to occur in the Atoka formation. The writers have not examined the rocks exposed in that area in detail

[21] Memorandum dated May 29, 1936.

[22] H. D. Miser, *op. cit.*, p. 979.

[23] H. D. Miser, "Geologic Map of Oklahoma," *U. S. Geol. Survey* (1926).

and must, consequently, classify them as undifferentiated Pennsylvanian.

CORRELATION OF ROCK FACIES IN OUACHITA AND ARBUCKLE MOUNTAINS

Two facies of rocks, each ranging in age from Cambrian to Lower Pennsylvanian (Pottsville) are represented in southeastern Oklahoma. Rocks of one facies, described in the preceding pages, are typically developed in the greater part of the Ouachita Mountain region of Arkansas and Oklahoma. The rocks of the other facies are found in the Arbuckle Mountain region and at four places in the northern part of the Ouachita Mountains; deep drilling has shown that they underlie extensive areas north and west of the Ouachita Mountains.

TABLE I
PRE-PENNSYLVANIAN SEQUENCE OF OUACHITA MOUNTAINS

Age	*Formation*	*Lithologic Character*
Devonian (?)	Arkansas novaculite	Novaculite and shale
Devonian		
Silurian	Missouri Mountain shale	Red and green hard siliceous shale
	Blaylock sandstone	Sandstone with some interbedded dark shale
Ordovician	Polk Creek shale	Black shale (in Potato Hills and Black Knob Ridge overlain by brown shale)
	Bigfork chert	Chert with a little limestone and black shale
	Womble shale	Dark shale with some sandstone and lenses of limestone
	Blakely sandstone	Dark quartzitic sandstone and shale
	Mazarn shale	Dark colored clay shale and a little limestone; locally altered to slate
Ordovician (?)	Crystal Mountain sandstone	Sandstone and thin coarse conglomerate
Cambrian	Collier shale	Chiefly bluish black shale and a little limestone

Rock facies characteristic of Ouachita Mountains.—Pre-Pennsylvanian rocks of the facies characteristic of the greater part of the Ouachita Mountains are exposed in Black Knob Ridge, a small area on Frounterhouse Creek about 6 miles south of Black Knob Ridge, the Potato Hills, and large areas in McCurtain County in Oklahoma (Fig. 1) and extensive areas in the Arkansas part of the Ouachita Mountains. The rocks exposed in those areas, as shown in Table I, are dominantly clastic sediments, shale and sandstone, together with cherts and novaculites. Limestone is present only in small amounts.

The faunas consist mostly of graptolites, inarticulate brachiopods, trilobites, conodonts, and siliceous fossils such as radiolaria and spicules.

The majority of them are planktonic forms, whereas most of the remainder are chiefly bottom-dwellers which do not require a shallow-water environment. In other words, the faunas of these rocks are composed primarily of forms which sank from the surface and of

TABLE II

PRE-PENNSYLVANIAN FORMATIONS OF ARBUCKLE MOUNTAIN REGION

Age		*Formation*	*Lithologic Character*
Mississippian		Caney shale	Black shale with septarian and phosphatic concretions
		Sycamore limestone	Dense limestone
Devonian (?)		Woodford chert	Dark chert and shale
Devonian	Hunton formation	Bois d'Arc limestone	Limestone with some chert
		Haragan shale	Calcareous shale
		Henryhouse shale	Calcareous shale
Silurian		Chimneyhill limestone	Limestone, oölitic, glauconitic, and crinoidal
Ordovician		Sylvan shale	Black shale at base with green shale above
		Viola limestone	Limestone with some chert
		Simpson group	Sandstone, limestone, and calcareous shale
		Arbuckle limestone	Limestone, magnesian limestone, and dolomite
Cambrian		Reagan sandstone	Arkose, sandstone, calcareous sandstone, and shale

those bottom-dwellers which are not particularly dependent upon light, shallow water, and a firm, hard bottom. The absence of littoral and shallow-water forms, such as articulate brachiopods, pelecypods, gastropods, and cephalopods is particularly noticeable, and this absence is the most striking difference between the faunas of the rocks of the Ouachita Mountains and those of the Arbuckle Mountains. It lends strong support to the idea that the rocks of the Ouachita Mountains were deposited in regions which were remote from shore lines of that time. Many of the species, particularly the planktonic forms, found in the Ouachita Mountains are also found in the Arbuckle Mountains, where they are associated with typical littoral and shal-

low-water forms. This indicates that the two areas were connected at many times during the early Paleozoic.

Rock facies characteristic of Arbuckle Mountains.—The pre-Pennsylvanian rocks of the facies characteristic of the Arbuckle Mountains are exposed over wide areas in and near the Arbuckle Mountains (Fig. 1). Deep drilling has shown that rocks of that facies also underlie large areas west and north of the Ouachita Mountains in Oklahoma. The rocks of the Arbuckle Mountains, as shown in Table II, are predominantly limestone, some of which are locally very cherty, together with some thin units of shale and sandstone. The faunas present in the rocks are highly varied with rather a full representation of thick-shelled calcareous forms predominating over the thin-shelled chitinous and siliceous forms.

Facies represented in Black Knob Ridge.—The rocks of Black Knob Ridge are practically identical both in lithologic character and faunas to rocks exposed in the Potato Hills, Oklahoma, and are only slightly less similar to rocks exposed in McCurtain County, Oklahoma, and over large areas in the Arkansas part of the Ouachita Mountains. At many places in the Arkansas and McCurtain County part of the Ouachita Mountains metamorphism has modified the lithologic character of the rocks but has not destroyed the essential similarity to those of Black Knob Ridge. The Blaylock sandstone, which is present between the Polk Creek and Missouri Mountain shales at many places in McCurtain County, Oklahoma, and in Arkansas, is absent in Black Knob Ridge, but the presence of a pronounced unconformity at the base of the Missouri Mountain shale in Black Knob Ridge indicates that the Blaylock sandstone is absent because of non-deposition or pre-Missouri Mountain erosion. The most pronounced difference in lithologic character between rocks in Black Knob Ridge and rocks farther east in the Ouachita Mountains is in the Bigfork chert, which contains somewhat more abundant limestone in its lower 410–510 feet in Black Knob Ridge than in any other known area in the Ouachita Mountains. That feature led Decker[24] to extend the name Viola limestone from the Arbuckle Mountains, and apply it to the unit here designated the Bigfork chert in Black Knob Ridge. The Viola limestone of the Arbuckle Mountain region as described by Decker[25] is characteristically a limestone containing chert nodules which are locally so abundant as to make up the greater part of some beds but

[24] C. E. Decker, "Viola Limestone, Primarily of the Arbuckle and Wichita Mountain Regions, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 12 (December, 1933), pp. 1407–08.

[25] C. E. Decker, *op. cit.*, p. 1410.

in general represent only a small percentage of the entire formation. The Bigfork chert of Black Knob Ridge is primarily a bedded chert formation containing far less than 50 per cent limestone even in the sections where calcareous material is most abundant. The abundance of siliceous spicules and radiolaria in the Bigfork chert indicates that siliceous material was present in considerable abundance in the sediments that formed the Bigfork chert and probably constitute the source of much of the chert-forming silica. The presence in the original sediments of at least a considerable part of the silica that has formed chert in the Bigfork constitutes a valid difference from the original sediments of the Viola limestone and suggests that the two formations are of at least partly different facies. According to Decker[26] the fauna of the Viola limestone is a highly varied one made up of abundant brachiopods, trilobites, conularids, and graptolites, together with two sponges. The fauna of the Bigfork chert of Black Knob Ridge is much less varied and is dominated by graptolites. Two species of trilobites, fragments of brachiopods, abundant sponge spicules, radiolaria, and conodonts comprise the remainder of the fauna. The trilobites and fragments of brachiopods are smaller than those of the same species in the Viola limestone. These faunal differences indicate that the conditions under which the two formations were deposited were markedly different. The alternating sequence of non-calcareous bedded chert and black shale in the upper part of the Bigfork chert has no lithologic similarity to any part of the Viola limestone, and is additional evidence of a difference in facies between the two formations. The greater abundance of limestone in the Bigfork chert in Black Knob Ridge than in the areas farther east in the Ouachita Mountains does suggest, however, that in Bigfork time the Ouachita and Arbuckle basins of sedimentation were connected and that there was a gradual change westward from more siliceous deposits to more calcareous deposits. It is the writers' opinion that northwestward thrusting along the Choctaw fault has moved the rocks of Black Knob Ridge closer to the rocks of the Arbuckle Mountains than they were at the time of deposition and has, therefore, covered beneath the overthrust blocks a part of the transition zone, with the result that the change in facies is abrupt in present exposures though it was probably gradual in the original sediments.

Several features other than the variation in the amount of limestone in the Bigfork chert are at least suggestive of the existence at various times of connections between the two basins of deposition of rocks of the facies characteristic of the Arbuckle and the Ouachita

[26] C. E. Decker, *op. cit.*, p. 1415.

mountains. Decker[27] has called attention to the presence in the basal part of the Viola limestone of dark shales that have some of the characteristics of the Womble shale, and also states that, on the evidence of graptolites, the upper part of the Womble shale is equivalent in age to the part of the Viola limestone that contains those shales. Moreover, many of the graptolites collected from the dark shales in the lower part of the Viola appear to be conspecific with the forms found in the upper zone of the Womble shale on Black Knob Ridge. One exposure of the shales in the basal part of the Viola limestone in the Arbuckle Mountains was visited by the writers under the guidance of Decker, and the lithologic similarity to beds in the upper part of the Womble shale of Black Knob Ridge was apparent. The presence of those beds in the Arbuckle Mountain region at the same horizon as similar beds in Black Knob Ridge is strongly suggestive of a connection between the two areas during at least a part of Womble time.

There is a marked similarity in some exposures between the lithologic character of the basal part of the Sylvan shale and the Polk Creek shale of the Black Knob Ridge. The Polk Creek shale at the base is made up of black shale that grades upward into brown platy shale. The Sylvan shale is characteristically a green clay shale with a local development of dark shale at the base. It is possible that the Polk Creek shale is equivalent to the dark, basal part of the Sylvan shale. Such equivalence is suggested both by the lithologic similarity and by the fact that *Dicellograptus complanatus*, which is common throughout the Polk Creek shale in Black Knob Ridge, is, according to Decker,[28] confined to the basal part of the Sylvan shale. The partial similarity in lithologic character of the two formations, together with the fact that the green shale phase of the Sylvan may not be represented in the Polk Creek, suggest that the basins in which they were deposited were connected.

There is considerable lithologic similarity between the black shales and cherts of the Woodford formation of the Arbuckle Mountains and some beds in the upper half of the Arkansas novaculite of Black Knob Ridge, units that are of equivalent age.[29] In addition to the lithologic similarity, the included faunas are similar both as to individual species and as to type. Spores, silicified wood, conodonts,

[27] C. E. Decker, "Some Tentative Correlations on the Basis of Graptolites of Oklahoma and Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 3 (March, 1936), p. 306.

[28] C. E. Decker, "Graptolites of the Sylvan Shale of Oklahoma and the Polk Creek Shale of Arkansas," *Jour. Paleon.*, Vol. 9, No. 8 (December, 1935), p. 702.

[29] C. L. Cooper, "Some Conodonts from the Arkansas Novaculite, Woodford Formation, Ohio Shale, and Sunbury Shale," *Jour. Paleon.*, Vol. 5 (1931), pp. 143–51.

lingulae, and orbiculoidia are common in both formations. The similarity of these two units, together with the pronounced dissimilarity of each to any other units within the overlying and underlying sequence of rocks, suggests strongly that the basins in which they were deposited were connected.

From the foregoing discussion it is apparent that the rocks of Black Knob Ridge belong to a facies common to the greater part of the Ouachita Mountains and dissimilar in many respects to the facies represented in the Arbuckle Mountains, although the distance from Black Knob Ridge to the Arbuckle Mountains is only about 15 miles. It seems evident to the writers, however, that there are sufficient points of similarity between the rocks of Black Knob Ridge and those of the Arbuckle Mountain region to show that the basins of deposition of the two facies were connected at least intermittently.

STRUCTURE

Black Knob Ridge lies at the west side of the Oklahoma structural salient of the Ouachita Mountains.[30] The deformation of the rocks in that salient was produced by compressive movements from the southeast, and the frontal part of the salient appears to have been thrust northwestward a distance of at least 20 miles. The salient is characterized by long roughly concentric overthrust faults which bound thrust sheets of northwesterly trend. The Choctaw fault, which forms the west boundary of Black Knob Ridge throughout most of its length separates the Oklahoma structural salient of the Ouachita Mountains from the Arkansas-Oklahoma coal basin, which lies farther west and north. The coal basin is characterized by long steeply folded anticlines, locally broken on their crests by reverse faults, and separated by broad synclines. The intensity of the folding in the coal basin is greatest near the Ouachita Mountain front and diminishes progressively northwestward.

Northeast of Stringtown, Black Knob Ridge is bounded on the northwest by the Ti Valley fault, along which Ordovician strata have been thrust northwestward onto Pennsylvanian strata. South of Stringtown, where the Ti Valley and Choctaw faults join, it is bounded on the west by their southwesterly continuation, which is called the Ti Valley-Choctaw fault. Along this fault Ordovician strata have been thrust northwestward onto Pennsylvanian and Mississippian strata. In general, the rocks of Black Knob Ridge dip steeply eastward away from the boundary faults and beneath beds of the Lower

[30] H. D. Miser, "Relation of Ouachita Belt of Paleozoic Rock to Oil and Gas Fields of Mid-Continent Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 8 (August, 1934), p. 1063.

Pennsylvanian (Pottsville) Stanley shale. Several minor thrust faults and steeply plunging folds interrupt the steep east dips, however, and present some evidence that the present structure of Black Knob Ridge is not due to simple overthrusting normal to the strike of the Ti Valley and Ti Valley-Choctaw fault.

Along Black Knob Ridge several minor reverse faults and two steeply plunging fold couples are present. Each fold couple consists of an anticline, that plunges steeply northeastward, bordered on the northwest by a steeply plunging syncline. Each plunging fold couple is situated immediately east of a double curve in the trend of the Ti Valley-Choctaw fault, so that the trace of the fault tends to parallel the outcrop of the lowest competent bed (base of the Bigfork chert) in the fold couple. It is the writers' opinion that the fold couples were produced by a northward component of movement in the overthrust block of the Choctaw-Ti Valley fault. During the earlier part of the movement the beds in the overthrust block probably lay parallel with the fault plane and had therefore the form of an incipient anticline and syncline whose plunging axes lay parallel with the fault plane. Later movement upward and northward in the overthrust block probably accentuated those incipient folds. As the northward trending component of pressure was transmitted along the strike of the competent beds, it is probable that at the point of change in strike the pressure trended to move the east flank of the incipient anticline northward and produce drag on the west flank, thus accentuating both the incipient anticline and syncline and producing fold couples of the type now present. Such movements would produce, between the fault plane and the base of the lowest competent bed in the fold couple, a zone of reduced pressure into which the intervening incompetent shale that underlies the lowest competent bed involved in the fold couples would be squeezed. The incompetent Womble shale which lies adjacent to the Ti Valley-Choctaw fault in both couples has evidently been subjected to such a local deformation, as, in both areas, it is highly contorted and slickensided, although elsewhere in Black Knob Ridge it shows only minor contortion.

Six minor overthrust faults break the strata in Black Knob Ridge near Stringtown. The faults trend eastward and the strata on the south side of each fault have been thrust upward in relation to the strata on the north side. The stratigraphic displacement on each of the two largest faults is about 1,000 feet and the total displacement on all of the faults is about 3,000 feet. The faults begin at the point of trend change in the Ti Valley fault and continue northward for about 1½ miles so that they lie within an arc formed by the Ti Valley fault.

It is the writers' opinion that the minor faults were produced by the northward component of movement on the east side of the Ti Valley-Choctaw fault. Such northward movement was transmitted along the strike of the competent beds. At the point of trend change in the Ti Valley-Choctaw fault the northward pressure was in part exerted against the buttress of the lower side of the Ti Valley fault and relief of pressure by folding was difficult. The resistance offered by the buttress present on the outside of the arc of the Ti Valley-Choctaw fault was so great that the strata were broken by southward-dipping fault planes along which the strata on the south side moved northward, thus relieving the northward component of the pressure.

Near the northeast end of Black Knob Ridge the strike of the strata turns northwestward and they end against a thrust fault of northeasterly trend that branches off from the Ti Valley fault near Grant's Gap. North of that fault the strata of Black Knob Ridge have been offset westward and are present in a short northward-trending belt between the fault just mentioned and the Ti Valley fault. This offset in the strata may be due to northeastward movement on the south side of the more southerly of the two thrust faults, but more probably is due to uplift of the eastward-dipping beds on the south side of the fault, followed by erosion to a common level.

Two minor thrust faults break the strata of Black Knob Ridge near and in the valley of North Boggy Creek, but exposures of the rocks in the zone of faulting are so poor that little can be determined as to the nature of the faults.

A low-angle thrust fault plane is exposed in a road cut on the main highway southeast of Atoka in the SE. cor. of Sec. 14, T. 2 S., R. 11 E. In the eastern part of its exposure the fault plane is practically horizontal, but near its west side it rises westward at an angle of about 20°. Along the fault, strata in the Bigfork chert have been thrust westward over older strata in the upper part of the Womble shale. The fault continues southward and cuts across all of the strata of Black Knob Ridge, the strata on the east side having been offset northward in relation to those on the west side of the fault.

STRUCTURAL RELATION OF BLACK KNOB RIDGE TO ROCKS OF FACIES CHARACTERISTIC OF ARBUCKLE MOUNTAINS

Eastward overlap of the Atoka formation onto the Springer formation just west of Black Knob Ridge, together with the presence in the Atoka formation of pebbles derived from those parts of the Caney shale or the Springer formation that lay to the east at the time of Atoka deposition, indicates that an uplift of strata that belong to the

sequence of the Arbuckle Mountains lay near the present position of Black Knob Ridge in Atoka time. That uplift existed prior to the development of the Choctaw and Ti Valley faults, as those faults cut strata in the Atoka formation and are consequently later than Atoka. It seems probable that the preëxisting uplifted mass served as the buttress over which the strata on the southeast side of the Choctaw-Ti Valley fault moved and thus controlled the location of the faults and of Black Knob Ridge.

The evidence just cited indicates that the rocks of the facies of the Ouachita Mountains now exposed in Black Knob Ridge have not only been thrust northwestward to within 15 miles of the Arbuckle Mountains but have also been thrust over strata of the Arbuckle facies that are now concealed beneath the Choctaw and Ti Valley fault planes.

MEASURED STRATIGRAPHIC SECTIONS

Section Exposed in Grant's Gap, SE. ¼, NW. ¼ of Sec. 10, T. 1 S., R. 12 E.

	Feet
Arkansas novaculite	
1. Novaculite, light gray, thick-bedded partly covered	5
2. Shale, red and green, hard, sandy and flaky	10
3. Novaculite, light gray, in thick beds, partly covered	190
Missouri Mountain shale	
4. Shale, red and green, hard, and flaky	12
5. Conglomerate, vitreous siliceous cement, containing pebbles from sand size up to 1 inch in diameter; pebbles are sand, green shale, and chert; one fossil found	2
6. Shale, red and green, hard and flaky, with alternating bands of black sandstone and chert; fossiliferous	18
7. Shale, green, hard, and siliceous to clayey with a few 1–3-inch bands of black soft sandstone and several 1-inch chert bands	55
8. Chert and cherty shale, white to apple-green, in bands from paper thickness to 3 inches in thickness, weathers light gray	20
9. Shale, green, siliceous, containing chert fragments and sand grains	3
10. Unconformity. Contact of Missouri Mountain shale and Bigfork chert	
Bigfork chert	
11. Chert; very thick-bedded with some thin chert partings; no limestone present; black paper shale throughout this zone but most abundant in upper half where it is about 40 per cent of the section; chert black-to-dark brown and finely laminated parallel with bedding; shale contains graptolites, conodonts, and orbiculoids	188
12. Limestone, gray, coarsely crystalline, with about 50 per cent dark gray chert; graptolites present, strong petroliferous odor; beds 1 foot thick at bottom, decreasing upward	40
13. Covered interval	20
14. Chert, gray-to-buff containing bands of limestone 1 inch thick that constitute about 5 per cent of unit; entire section weathers gray	270
15. Chert, gray to brown, with some finely crystalline gray limestone in beds as thick as 6 inches	80
16. Flint, black, very hard, and badly broken	2½
Womble shale	
17. Shale, cherty, buff-to-black in bands 3–5 inches thick; strong petroliferous odor and graptolites	45
18. Shale, black, hard, and siliceous in bands 3–5 inches thick with softer black	

	Feet
1-inch paper shale partings; shale becomes more siliceous and somewhat thicker-bedded toward top; gives off strong odor of petroleum when freshly broken; contains graptolites	40
19. Shale, hard, green, weathers brownish, sandy, contains graptolites	22
20. Shale, soft and greenish clay shale that weathers to green-to-buff clay	144
21. Covered interval—fault zone	9
Undifferentiated Pennsylvanian beds at north side of exposure	
22. Sandstone, brown, hard, fine-grained, badly broken and slickensided	2
23. Covered interval	16
24. Shale, black-to-blue-black, hard, badly shattered and slickensided	33
25. Shale, tan, sandy, badly broken, weathers tan	30
26. Covered interval	60
27. Sandstone, hard, brown, slickensided, and broken	2

SECTION EXPOSED IN VALLEY OF SMALL STREAM IN SE. ¼, SW. ¼ OF SEC. 21, T. 2 S., R. 12 E.

Stanley shale	
1. Siltstone, pale green-to-light brown, hard, brittle, in bands of paper thickness to 3 inches in thickness; some beds are harder than others and form ledges; conodonts in lower part; covered above this point	95
2. Sandstone, fine-grained, dense, massive, hard, gray; contains small angular chert and novaculite fragments and sub-angular-to-rounded quartz grains	9
3. Unconformity. Irregular contact of Stanley shale on Arkansas novaculite	
Arkansas novaculite	
4. Novaculite, green, brown, and gray, in bands 1–6 inches thick	32
5. Shale, red and green, hard and gritty; contains bands of novaculite 2 inches thick and band of black paper shale 1½ inches thick near middle	7
6. Covered interval	18
7. Novaculite, alternating with bands of black tough paper shale containing conodonts, and containing some beds of hard green shale that breaks into rectangular fragments; shale constitutes about 5 per cent of unit	57
8. Novaculite, mostly in beds 2–4 inches thick with a few beds as thick as 6 inches; contains beds of hard, green shale as thick as 3 feet that breaks into rectangular fragments	120
Missouri Mountain shale	
9. Covered interval	35
10. Shale similar to that below but contains several sandstone beds 2½–4 inches thick; most of sandstone is finely laminated, fine-grained, dense, and hard, but some is medium-grained and fairly soft; sandstone is white, speckled with buff on interior, and weathers white, and many of pieces bear fucoid markings	14
11. Shale, red and green, hard, splintery, and gritty, greasy luster	4
12. Shale, similar to that below contains three chert beds 1 inch thick that are finely laminated	2
13. Shale, apple-green with some variegated red and green, hard and splintery, greasy luster	15
14. Shale, much weathered to tan clay	10
15. Unconformity. Contact of Bigfork chert and Missouri Mountain shale	
Bigfork chert	
16. Gray chert in beds 6 inches thick	

SECTION EXPOSED ON CLIFF NORTH OF NORTH BOGGY CREEK IN NW. ¼, SE. ¼ OF SEC. 29, T. 1 S., R. 12 E.; SECTION STARTS ON EAST SIDE OF HIGH RIDGE AND ENDS IN OLD QUARRY ALONG OLD ROAD FROM ATOKA TO STRINGTOWN

Bigfork chert (top covered, but practically entire formation is present in described section)	
1. Chert in beds ranging from 4 inches to 2 feet in thickness, black-to-brown, banded, regularly bedded, contains black paper shale partings	45

	Feet
2. Chert in beds ranging from 1 inch to 1 foot in thickness, black-to-brown, banded and contains partings of black paper shale	56
3. Chert and limestone, similar to that below except that limestone constitutes about 50 per cent of zone	117
4. Covered interval	33
5. Chert and limestone; chert banded brown and gray; limestone is gray, finely crystalline and occurs in bands and stringers that constitute about 10 per cent of entire zone	40
6. Covered interval	21
7. Chert and limestone, similar to underlying zone except that limestone constitutes 10 per cent or more of interval	105
8. Chert and limestone; chert banded, brown-to-gray, and in thin beds; limestone dense, gray, as stringers and bands that constitute about 5 per cent of entire zone	101
9. Chert, exposed at few places in covered zone	30
10. Chert, banded light and dark gray in thin beds	36
11. Chert, brown, massive-to-irregularly bedded	8
12. Chert, dark gray, thin-bedded	13
13. Chert, dark gray, irregularly bedded	4
14. Chert, dark gray and thin-bedded	5
Womble shale	
15. Shale, brown-to-black, hard and cherty, much shattered	17
16. Fault, strike N. 60° E., dip of plane 45° N. 30° W., displacement indeterminate but probably small	
17. Shale, dark and cherty, weathers light-colored and platy, some beds contain coarse, rounded, frosted sand grains	39
18. Shale, hard, dark brown-to-black, blocky, weathers to light-colored thin plates	9
19. Shale, hard and black in plates ⅛–¼ inch thick	3
20. Shale, black and flaky, weathers gray-to-black	7
21. Shale, hard, black to brown, gritty with well rounded, coarse, frosted sand grains; shale exposed in beds 2–10 inches thick but weathers to thin, light gray plates	6
22. Shale, dark gray-to-brown, some appears slightly green on weathered surface but most of shale weathers gray	12
23. Shale, gray-to-brown, hard, siliceous	9
24. Shale, harder than that below, blocky, black-to-brown	11
25. Shale, brown, weathers greenish brown, soft, clayey	10

SECTION OF ARKANSAS NOVACULITE EXPOSED ON ANTLERS ROAD. SECTION BEGINS ON EAST SIDE OF BLACK KNOB RIDGE AND EXTENDS APPROXIMATELY TO BASE OF ARKANSAS NOVACULITE

1. Novaculite, light brown-to-gray, in beds as thick as 10 inches with some interbedded buff shale	30
2. Red and green, siliceous and flaky shale containing some thin bands of novaculite; conodonts very abundant in some zones	45
3. Red and green flaky siliceous shale containing beds of novaculite as thick as 9 inches; shale contains some conodonts	54
4. Novaculite, black-to-gray, in thin beds as thick as 5 inches, some green shale and numerous partings of black paper shale, some pyrite, spores, conodonts, and lingulae	100
5. Massive and thin-bedded gray novaculite, with thicker beds in upper part, some thin green shale and one zone of black siliceous shale in middle part	130

SECTION EXPOSED IN SMALL EASTWARD-FLOWING STREAM AND OLD ASPHALT PIT IN NE. ¼, NW. ¼ OF SEC. 32, T. 1 S., R. 12 E.

Stanley shale	
1. Shale, cherty; section covered east of this point	20
2. Sandstone	2
3. Shale, cherty, greenish, resembles green novaculite but can be scratched with knife	8

	Feet
4. Sandstone, fine-to-medium grains of quartz and chert; quartz grains sub-rounded and chert grains angular-to-sub-angular; contains fragmental plant material	1½
Arkansas novaculite	
5. Novaculite, mostly green, some brown with brecciated appearance, in beds ranging from 2 inches to 1 foot thick	25
6. Covered interval	12
7. Shale, red and green, hard, flaky, and gritty	12
8. Covered interval	16
9. Novaculite, in thin beds alternating with hackly green shale, and containing 1–3-inch beds of black paper shale	49
10. Novaculite, mostly in thin beds but some beds are as thick as 1 foot, brown, and appear brecciated	39
11. Novaculite, thin-bedded, white, gray, and green, with hard green shale partings	26
12. Mostly covered, with a few beds of novaculite showing	32
13. Novaculite, thin-bedded (1–2 inches) with a few thicker beds, white and apple-green, and hard siliceous green shale partings	63
Missouri Mountain shale	
14. Covered interval	20
15. Shale, dark green, sandy, hard, and flaky; contains a few 1-inch bands of fine-grained sandstone	20
16. Grahamite	1
17. Covered interval	10
18. Conglomerate, vitreous siliceous cement, fragments from sand size to 1 inch in diameter; pebbles are sand, chert, and green shale	2
19. Covered interval; contact between Polk Creek shale and Missouri Mountain shale in this zone	54
Polk Creek shale	
20. Shale, brown, soft, silty, contains graptolites, much contorted	12

SECTION EXPOSED IN GULLY ON NORTH SIDE OF BLACK KNOB RIDGE IN SE. ¼, SE. ¼ OF SEC. 9, T. 1 S., R. 12 E.

Section starts with uppermost bed of Womble shale and extends down to base of exposure of Womble	
1. Shale, brown-to-black in alternating soft and very hard cherty bands, both of which weather very light gray and contain abundant graptolites	30
2. Shale, light gray with slight brownish tinge, soft, fissile, and contains abundant graptolites	4
3. Shale, somewhat harder than that underlying, very light brown, occurs in bands as thick as 1 inch; some hard chert shale in nodular masses; contains abundant graptolites	6
4. Shale, soft and clayey, light brown-to-olive-green; contains graptolites	5
5. Shale, platy, light brown; contains graptolites	4
6. Shale, soft, platy and light brown where fresh but weathers to flaky fragments and green clay; contains graptolites	5
7. Shale, weathered, flaky and bright green; contains graptolites	130
8. Sandstone, soft, black, made up of large, well rounded, frosted sand grains in soft, dark matrix	1
9. Shale, flaky to clayey, green, much weathered	10
Section covered for about 100 feet to where beds of Pennsylvanian age are exposed	

DISCUSSION

J. H. GARDNER, Tulsa, Oklahoma (discussion received, December 17, 1936).

Origin of Talihina chert.—There are unquestionably several different origins and placements of chert deposits. There is always the danger of work-

ing up a thesis on the origin of something and then making a too wide application of the conclusions. I think this has been true with respect to the origin of chert and also of bentonite. I shall touch briefly on the origin of bentonite in a later paragraph.

Silica is a well known replacing agent. The fact that it has replaced fossil wood by the metasomatic process shows the natural tendency for silica to replace other materials, particle by particle by exchange of position. This process has been demonstrated in the laboratory by subjecting corals to the slow percolation of hydrous silica with the result that it replaces calcium carbonate.

According to Twenhofel, chert is a crypto-crystalline variety of quartz of various colors ranging from gray, dark or black to red and green. It usually contains some impurities of iron oxide, calcium carbonate, magnesium carbonate, alumina, and iron pyrites. It occurs in many places as pure silica. It is common in all the sedimentary series, ordinarily in the form of concretions or irregular masses in limestone and shale. It occurs also in the form of thick, stratified deposits at several horizons especially in the Paleozoic rocks, but also in later deposits such as the Franciscan group in California. Some cherts are of a secondary or replacement nature, but others are syngenetic or original in deposition. It is therefore necessary in discussing chert to pick some particular occurrence and study that particular problem. The subject here under view is the Talihina section of the Black Knob Ridge and the Ouachita basin in Oklahoma, Arkansas, and Texas.

In my judgment, a recent paper by Rudolph Ruedemann and T. Y. Wilson on the eastern New York Ordovician cherts[1] fully covers the situation as it may be applied to the Talihina chert of the Black Knob Ridge section. One is a deposit in the Appalachian geosyncline and the other in the Ouachita geosyncline. Both are in the early Paleozoic rocks and involve parts of the Ordovician section. The geologic history and the orogeny of the two areas are similar and in many ways the chert deposits themselves are closely similar. In both provinces there is a decided contrast in rock facies and also a contrast in faunal content as compared with the foreland facies. The authors discuss the Hudson Valley cherts in much detail and establish a convincing argument that the chert is syngenetic and was deposited on the floor of a deep sea. They conclude that the stratified cherts were deposited as silica gel at a depth of approximately 12,000 feet. The fauna consists of graptolites, sponge spicules, radiolarians, and nothing else of particular note. Out of 51 slides used in petrographic work, 27 contained radiolarians. Recent oceanographic work supplementing that of the Challenger expedition has shown that radiolarian ooze occurs at depths ranging from 9,000 to 24,000 feet. Few are found at depths of less than 600 feet. They are normally pelagic or abysmal. They are not found in the North Sea and the Baltic, and very few are found in the Mediterranean. Graptolites, being associated with radiolarians and occurring chiefly in the shale partings, indicate that they, too, are common in deep sea water, though usually planktonic in the open sea.

The New York cherts belong to the Normanskill formation (Chazy and Black River) and the Deepkill formation (Beekmantown). Graptolites from the Stringtown shale have been correlated by Ulrich with the Normanskill fauna. The Bigfork chert or Viola equivalent is probably of somewhat

[1] Rudolph Ruedemann and T. Y. Wilson, "Eastern New York Ordovician Cherts," *Bull. Geol. Soc. America*, Vol. 47, No. 10 (October 31, 1936), pp. 1535–86.

younger age and the Arkansas novaculite is in part Devonian. However, regardless of the details in correlation, the cherts of the two areas are of a similar nature and were deposited in Paleozoic geosynclines. Mr. Hendricks reports radiolarians present in the cherts of Black Knob Ridge.

Ruedemann and Wilson attribute the abundance of silica to volcanic activity on the sea floor or to continental vulcanism at the time of deposition. Normally sea water contains very little silica. Radiolarians require it in quantity and relative abundance. The chert beds of Newfoundland are associated with bentonite and basalt; chert occurs there as beds between layers of pillow lava. The chert beds in New York like the beds in the upper part of the Talihina chert at Black Knob Ridge contain bentonite as partings. It is greenish bentonite or really metabentonite, the result of compaction, hardening, and dehydration. So, in my opinion, the land masses of Appalachia and Llanoria furnished volcanic material to the Appalachian and Ouachita geosynclines thereby supplying much silica to the sea water in Ordovician and other Paleozoic time. I agree fully with those who interpret the chert as syngenetic in origin. I would apply Ruedemann and Wilson's conclusions to the cherts in the Ouachita area. Volcanic activity on the sea floor or hot springs beneath sea-level may have been the main contributing factor to reasonably local occurrences of colloidal silica. In the Ouachita salient this volcanic activity continued to supply volcanic ash, bentonite, and some chert to the Stanley formation.

Now in regard to bentonite—though it has been found that some volcanic ash weathers to form bentonite, I have observed evidences which convince me that bentonite is given off directly by volcanoes and is associated with volcanic ash. However, I am convinced that bentonite is itself syngenetic. In the Birdseye limestone near High Bridge, Kentucky, there is a bed of bentonite about 6 feet thick that is intercolated between massive beds of pure limestone. It is pure bentonite of a greenish color that swells and becomes colloidal in water. However, only a few feet above, there is a bed composed chiefly of volcanic ash. Both these beds have been long subjected to weathering and the influences of ground water, but one remains volcanic ash and the other remains bentonite. Also, near the mouth of the Verdigris River in Oklahoma there is a thick bed of volcanic ash associated with the first deposits of the Arkansas River; in this bed there is a layer of pure bentonite about 10 inches thick. The ash has remained ash and the bentonite has remained bentonite. The two are distinct but closely associated. It is my belief that they were given off from volcanoes at the same time and place. The bentonite, being more colloidal, remains in suspension after the ash is thrown down, but quiet waters will finally precipitate the bentonite in the presence of some electrolyte. The same thing is true of cherts which are associated with bentonite layers. I think that clays of the fullers earth type are associated with the deposits. Both are syngenetic and were deposited at the contact of fresh water and saline waters along the coast. These occurrences bear out the conclusions of Twenhofel in his *Treatise on Sedimentation*, that much stratified chert is syngenetic and precipitated in sea water.

Southward continuation of the Choctaw fault.—In my opinion the thrust fault that bounds the Talihina chert at Black Knob Ridge continues in a southwesterly course toward the town of Caney, but before reaching that point it swings southeastward and continues in that direction until it intercepts the continuation of the fault that bounds the north side of

the Belton anticlinal block of the Arbuckle Mountains as shown on the Tishomingo and Atoka quadrangles. I believe the Belton anticline and the Tishomingo anticline continue their courses southeastward beneath the Cretaceous cover far out into the Ouachita basin and represent a Pennsylvanian orogeny older than that of the faults of the Ouachita area. The large thrust of later time pushed northwestward along the north side of these earlier structures so that the Ouachita faults continue their courses until they reach this older tectonics and then turn southeastward alongside of them until they possibly ride over and across them. It is my opinion that the Choctaw fault and some of the parallel faults of that series never did cut or over-ride the Belton and Tishomingo extensions at points near the Arbuckle Mountains and continue on into Texas parallel or coinciding with the boundary of the Ouachita sedimentary facies. I think they turn southeastward with the extension of the Arbuckle tectonics. If the thrust sheets of the Ouachita salient could be pushed back to their former position farther southeast, the Ouachita facies and the Arbuckle facies would probably connect at a distance of about 25 miles southeast of Black Knob Ridge. This theory permits a logical explanation of the klippes of Arbuckle rocks in Johns Valley by their being dragged into that position along thrust sheets at the time of the later orogeny that permitted the sheets to be thrust across the rocks of the Arbuckle facies. The writer would continue the Black Knob Ridge fault in the form of a lazy S, first toward the south and then toward the southeast for about 25 miles, then back along the north side of the Belton and Tishomingo blocks to the Arbuckle Mountains, except at the point of southeast junction the Ouachita thrust possibly cuts across the older fault. However, this trail would extend from the Ouachita facies back to the Arbuckle facies and somewhere to the southeast the two actually may connect unfaulted. In that same vicinity it is likely that the Washita fault which bounds the south side of the Arbuckle Mountains either terminates with the Tishomingo anticline or else swings around the east end of that structure to join the Washita tectonics.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGI TS
VOL. 21, NO. 1 (JANUARY, 1937), PP. 30-66, 17 FIGS.

ORIGIN AND DISTRIBUTION OF BARTLESVILLE AND BURBANK SHOESTRING OIL SANDS IN PARTS OF OKLAHOMA AND KANSAS[1]

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ABSTRACT

About 2 years have been spent by several members of a United States Geological Survey party in studying the buried oil- and gas-bearing Bartlesville and Burbank sands in Osage and Kay counties, Oklahoma, and Cowley, Butler, and Greenwood counties, Kansas. This work followed about 2½ years study of the Kansas area, made by Bass for the Kansas Geological Survey in coöperation with the United States Geological Survey, the results of which were presented before the Association meeting at Dallas and published in the *Bulletin* in 1934. The later work has also included an examination of the Bluejacket sandstone, which crops out in northeastern Oklahoma and southeastern Kansas, and certain of the beach deposits on the Atlantic coast and on the Gulf coast of Texas.

Stratigraphic cross sections made from well logs show that the Bartlesville sand is stratigraphically lower than the Burbank sand and that the shoestring sands of Greenwood, Butler, and Cowley counties, Kansas, are equivalent to the sands of the Burbank, South Burbank, and Naval Reserve oil fields of Oklahoma. The Bartlesville and Burbank sands are actually zones composed of numerous lenses of sand that occur within narrowly restricted limits in the Cherokee shale.

The Burbank sand bodies particularly occur in definite systems, called "trends," made up of lenses that are separated by gaps containing no sand. The individual sand lenses have an offset arrangement within the trends. Similar features are found in the systems of offshore bars on the Atlantic and Gulf coasts. The shapes in cross section of the shoestring oil-bearing sand bodies are similar to those of offshore bars. The composition and physical characteristics of the oil-bearing Bartlesville and Burbank sands are similar to those of the sands that form the modern offshore bars on the Atlantic and Gulf coasts. Many modern offshore bars, of which that at Cape Henry, on the Virginia coast, is an example, are made up of a series of overlapping beaches that have been preserved as ridges of sand trending parallel with the coast. These ridges represent lines of beach growth. The sand body of the main Burbank oil field, that of the Stanley stringer on its eastern margin, and the sand body of the South Burbank oil field appear to be characterized by features that may be growth ridges.

The studies indicate that the Bartlesville sand was deposited as a series of offshore bars along the western shore of the Cherokee sea during an early stage of the sea when the western shore migrated to and fro across a narrow strip of country in northeastern Oklahoma and southeastern Kansas. The Burbank sand bodies were deposited much later, after the Cherokee sea had expanded widely to the northwest. The trends of Burbank sand were deposited as offshore bars mainly during the Teeter-Quincy and Sallyards-Lamont stages of the Cherokee sea. The sand bodies of the Burbank and South Burbank oil fields are tentatively assigned to the Teeter-Quincy stage and are believed to have been formed by a series of overlapping beach deposits similar to those that form Cape Henry, Virginia.

[1] Read before the Association at the Tulsa meeting, March 20, 1936. Published by permission of the director of the United States Geological Survey. Manuscript received, October 24, 1936.

[2] United States Geological Survey.

[3] Tide Water Oil Company; formerly with United States Geological Survey.

[4] National Park Service, Omaha, Nebraska; formerly with United States Geological Survey.

It is recommended that, in prospecting for additional shoestring-sand oil fields, drilling sites be selected by projecting the known shoestring-sand trends in approximately straight lines similar to the trends of the systems of offshore bars on our present coasts, and not by meandering lines similar to stream courses. Inasmuch as modern offshore bars and the developed shoestring-sand bodies have an offset or *en échelon* arrangement within the systems and have gaps separating the individual sand bodies, these features should be expected in the projection of the sand trends into undeveloped territory.

INTRODUCTION

The oil- and gas-producing Bartlesville and Burbank sands of Kansas and Oklahoma occur in the lower part of the Cherokee shale (Fig. 5), which in this region is the oldest formation in the Pennsylvanian series. The sands characteristically occur in elongate bodies 50–150 feet thick, ½–2 miles wide, and 2–6 miles long (Fig. 1). These bodies are arranged in belts, some of them more than 50 miles long, to which the name "trends" has been applied.[5] In much of the area adjacent to the trends little or no sand occurs at the horizon of the lenses. Because of their distribution in elongate belts the sands are called "shoestring sands," and the oil pools are known as "shoestring fields." The Bartlesville sand occurs chiefly in eastern Osage County, Oklahoma, and the Burbank sand occurs in western Osage and eastern Kay counties, Oklahoma, and in Cowley, Butler, and Greenwood counties, Kansas. Shoestring-sand bodies occur, however, in a much larger region in eastern Kansas and Oklahoma than is shown in Figure 1.

According to Carpenter[6] oil was discovered in the Bartlesville sand near Bartlesville, Oklahoma, in 1897, and was being produced from this sand in Osage County, in the Boston pool near Cleveland, in the Avant pool near Avant, and near Bartlesville, as early as 1904–1906.[7] Oil fields in the Bartlesville sand were developed intensively in eastern Osage County, Oklahoma, after 1906. Oil was discovered in the Burbank sand in the large Burbank oil field in 1920, and the field was developed during the succeeding few years. Oil fields in Kansas in the Burbank sand (locally called "Bartlesville") were rapidly extended in 1922–1926,[8] although oil had been found there in the Burbank sand

[5] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), p. 1313.

[6] Everett Carpenter, "Oil and Gas in Oklahoma, Washington County, Oklahoma," *Oklahoma Geol. Survey Bull. 40*, Vol. 3 (1930), p. 139.

[7] Everett Carpenter, *op. cit.*, p. 139.
Bess Mills Bullard, "Digest of Oklahoma Oil and Gas Fields," *Oklahoma Geol. Survey Bull. 40*, Vol. 1 (1928), pp. 108, 117, 146.

[8] W. R. Berger, "The Relation Between the Structure and Production in the Sallyards Field, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), p. 276.

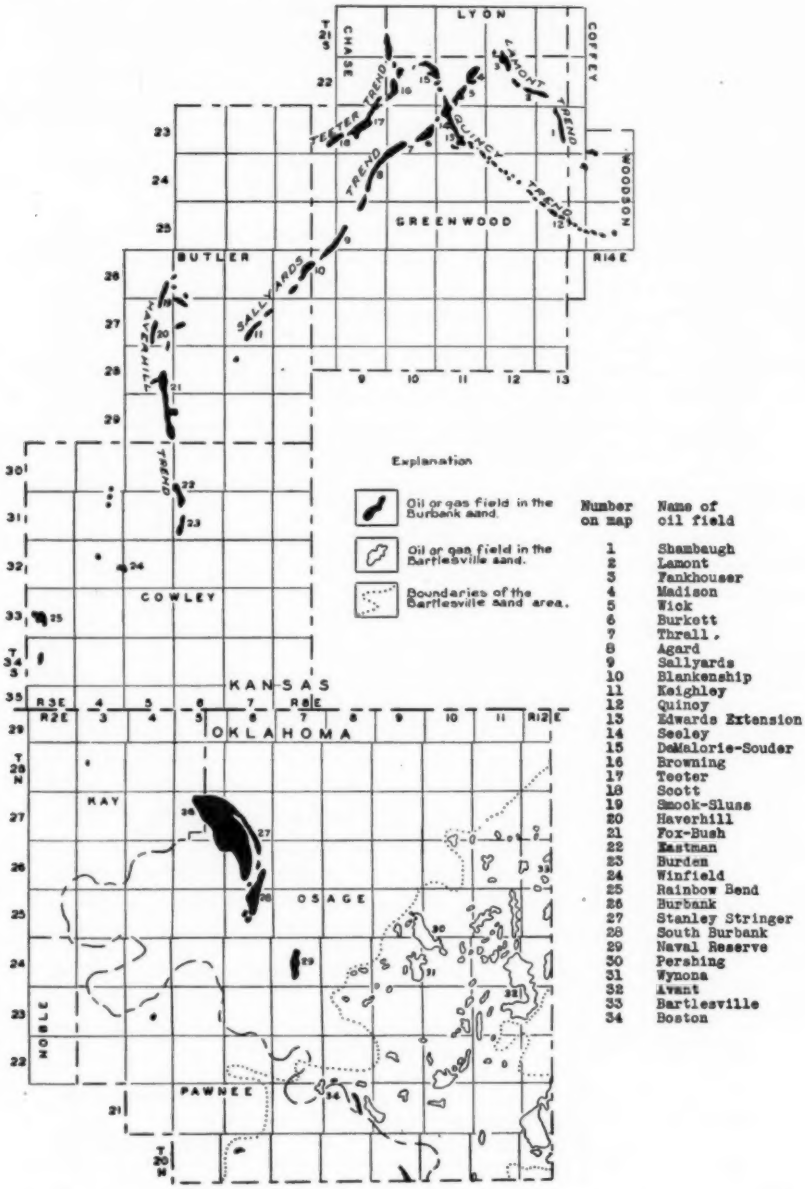

FIG. 1.—Map of parts of Oklahoma and Kansas showing oil and gas fields in Burbank and Bartlesville sands.

as early as 1917.[9] The South Burbank oil field, in western Osage County, Oklahoma, discovered in December, 1933, and still under development, is one of the most productive pools of this type. Its discovery and growth have stimulated new interest in the shoestring-sand region. In most localities in the region the gravity of the oil from the Bartlesville sand is about 31°–34° Baumé, and that from the Burbank sand is approximately 38°–40°. The depths to the sands range from about 1,200 feet in eastern Osage County, Oklahoma, to about 3,000 or 3,300 feet in Kay County, Oklahoma, and western Cowley County, Kansas.

The Burbank field in Osage and Kay counties, Oklahoma, on January 1, 1936, had yielded 188,000,000 barrels of oil, or an average of about 8,160 barrels to the acre. A few leases (160 acres each) in the field had produced more than 20,000 barrels of oil to the acre. In the South Burbank field the high initial yield of the wells, many of which produced 3,000–5,000 barrels of oil a day, and the large thickness of pay sand indicate that the average yield of oil to the acre here will exceed that of the Burbank field. Moreover, the South Burbank oil field is being operated as a unit and a high reservoir pressure is being maintained by returning gas to the sand. This method of operation is believed to be much more efficient than that used in the main Burbank field, and it constitutes an additional reason for the prediction that the ultimate average yield in the South Burbank field will exceed that of the Burbank field. Some leases in the Avant field, in eastern Osage County, Oklahoma, have produced more than 30,000 barrels of oil to the acre from the Bartlesville sand, but the average yield from the Bartlesville sand, in eastern Osage County may not exceed 4,000–6,000 barrels to the acre. Several shoestring fields in Kansas probably will have an ultimate yield of 7,000–8,000 barrels of oil to the acre, but others will yield considerably less. Hutchinson[10] has suggested that the average yield in the shoestring-sand oil fields of Butler and Greenwood counties, Kansas, which according to him occupy 30,000 acres, may be about 6,000 barrels to the acre.

Harve Loomis, "The Burkett-Seeley Pool, Greenwood County, Kansas," *ibid.*, Vol. 7, No. 5 (1923), p. 482.

Everett Carpenter, "Petroleum Development in Kansas During 1924," *Production of Petroleum in 1924, Amer. Inst. Min. Met. Eng.* (1925), pp. 154–55.

Henry Ley, "Oil Resources of Oklahoma and Kansas in 1926," *Petroleum Development and Technology in 1926, Amer. Inst. Min. Met. Eng.* (1927), p. 639.

[9] J. D. Northrop, *U. S. Geol. Survey, Mineral Resources of the United States, 1917*, Pt. 2 (1920), p. 769.

[10] N. M. Hutchinson, "Program of Gas and Air Repressuring in Eastern Kansas Proves Profitable," *Oil and Gas Jour.* (February 27, 1936), p. 33.

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The writers take pleasure in expressing their indebtedness to many Mid-Continent oil companies and individual geologists and operators for cordial coöperation in furnishing well logs, drill samples, and other data; to the Laughlin-Simmons Well Elevation Service, the Indian Territory Illuminating Oil Company, and other oil companies for well elevations; to H. B. Goodrich, Charles T. Kirk, Joseph D. McClure, and George D. Gibson, members of the United States Geological Survey party, for assistance; to Hugh D. Miser, under whose supervision the work was done, for helpful criticims and suggestions; to Howard Clark for many of the photographs used; and to W. H. Bradley and T. A. Hendricks for reading and criticizing the manuscript.

PURPOSE

The chief problem in the study of the Bartlesville and Burbank sands has been to determine the origin of the sand bodies and to apply the findings to the discovery of additional oil fields. The correct interpretation of the origin of the sand deposits is, therefore, not only of scientific interest but of commercial importance. The results of this study can be applied not only to Greenwood, Butler, Cowley, and adjacent counties in Kansas and to Osage and Kay counties in Oklahoma, but to a broad region in northeastern Oklahoma and eastern Kansas and probably to a large region in north-central Texas and to many other localities in the United States where deposits of similar type remain to be exploited for oil. As information has accumulated by the exploration for oil, particularly in Kansas, Oklahoma, and Texas, oil-bearing sand lenses, not wholly unlike the Bartlesville and Burbank sand bodies described here, have been found to be much more numerous and more productive of oil than was earlier believed. There very small dimensions and lack of structural expression at the surface make them difficult to locate, but the high quality of their oil, the longevity of the production from them, and their relatively shallow depth in many localities make their exploitation attractive to the oil producer.

The work of the writers indicates that there are several localities in the area studied (Fig. 1) that probably contain undiscovered shoestring oil fields and that these localities are worthy of intensive but intelligently directed prospecting. Because sandstone beds that originated by any one set of depositional processes form an areal pattern that is quite unlike that of a deposit formed by other processes, the determination of the origin and areal pattern of the Bartlesville and Bur-

bank sand bodies has a practical value in prospecting for new oil pools of the shoestring type. A geologist attempting to extend the shoestring sand trends into undeveloped territory will project one pattern beyond the known oil fields if he believes that the sands were formed by the filling of stream channels but a quite different pattern if he believes that the sand bodies originated as offshore bars similar to the bars on modern coasts.

If the Burbank sand in western Osage County, Oklahoma, and the adjacent region was laid down by an aggrading river, the distribution of the sand might produce a pattern similar to the sketch on the left in Figure 2, in which most of the wells that found Burbank sand have been included within the meandering boundary lines. If the sand bodies in that region were deposited as offshore bars, an interpretation similar to the sketch on the right in Figure 2, in which many of the wells that found Burbank sand have been included within the boundary lines of hypothetical systems of offshore bars, would appear more plausible.

FIELD STUDIES

The shoestring sands in Greenwood and Butler counties, Kansas, were studied by Bass for the Kansas Geological Survey in coöperation with the United States Geological Survey through a period of about 2½ years, beginning in 1930, and the salient facts which led to the conclusion that these sand bodies were deposited as offshore bars were published in this *Bulletin* in 1934.[11] Since that time the work on the shoestring sands has been extended southward by the writers to include Cowley County, Kansas, and Kay and Osage counties, Oklahoma.

During the summer of 1935, Bass, accompanied by H. D. Miser during a part of the time, studied the modern offshore bars on the eastern coast of North Carolina, Virginia, Maryland, Delaware, and New Jersey, shown in part in Figures 3 and 4. The offshore bars on the Gulf coast of Texas, between Port Arthur and the Rio Grande River, were examined by Kennedy and Bass in December, 1935. Aerial photographs of the coasts of many of the Atlantic seaboard states, made recently for the United States Coast and Geodetic Survey, were studied. Some study was made of sand collected from ancient Pleistocene beaches[12] which lie about 40 feet above the present sea-level, on

[11] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1313–45.

[12] C. W. Cooke, "Correlation of Coastal Terraces," *Jour. Geol.*, Vol. 38 (1930), p. 580.

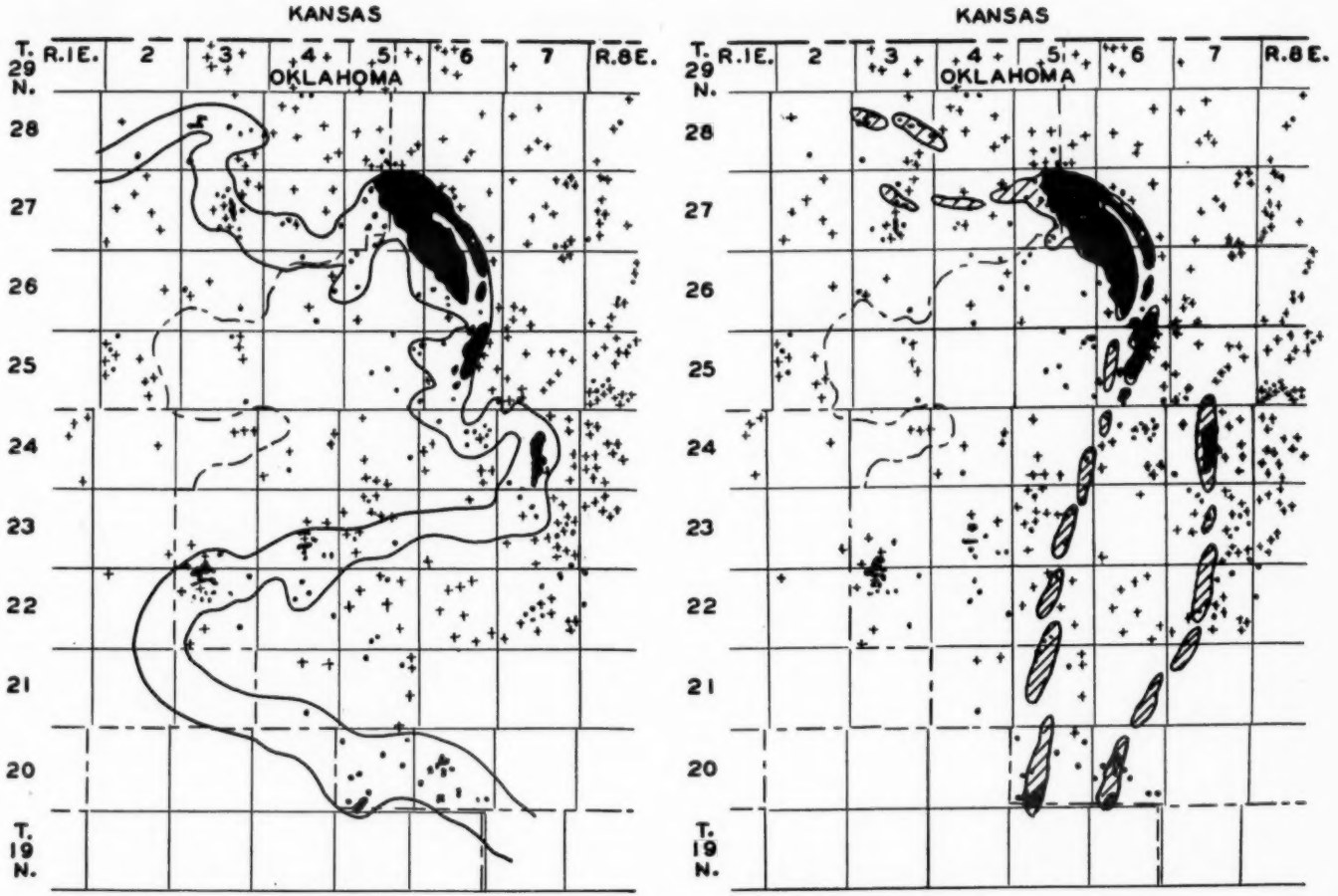

FIG. 2.—Sketch maps of parts of Osage and Kay counties, Oklahoma, showing two possible interpretations of distribution of Burbank sand. *Left:* Meandering boundary lines, similar to the course of a meandering stream, inclose nearly all wells that found Burbank sand. *Right:* Trends of hypothetical offshore bars, patterned after modern coast charts, include most wells that found Burbank sand. Solid black dots and areas indicate wells and fields, respectively, where Burbank sand is present. Plus signs indicate wells in which Burbank sand is absent.

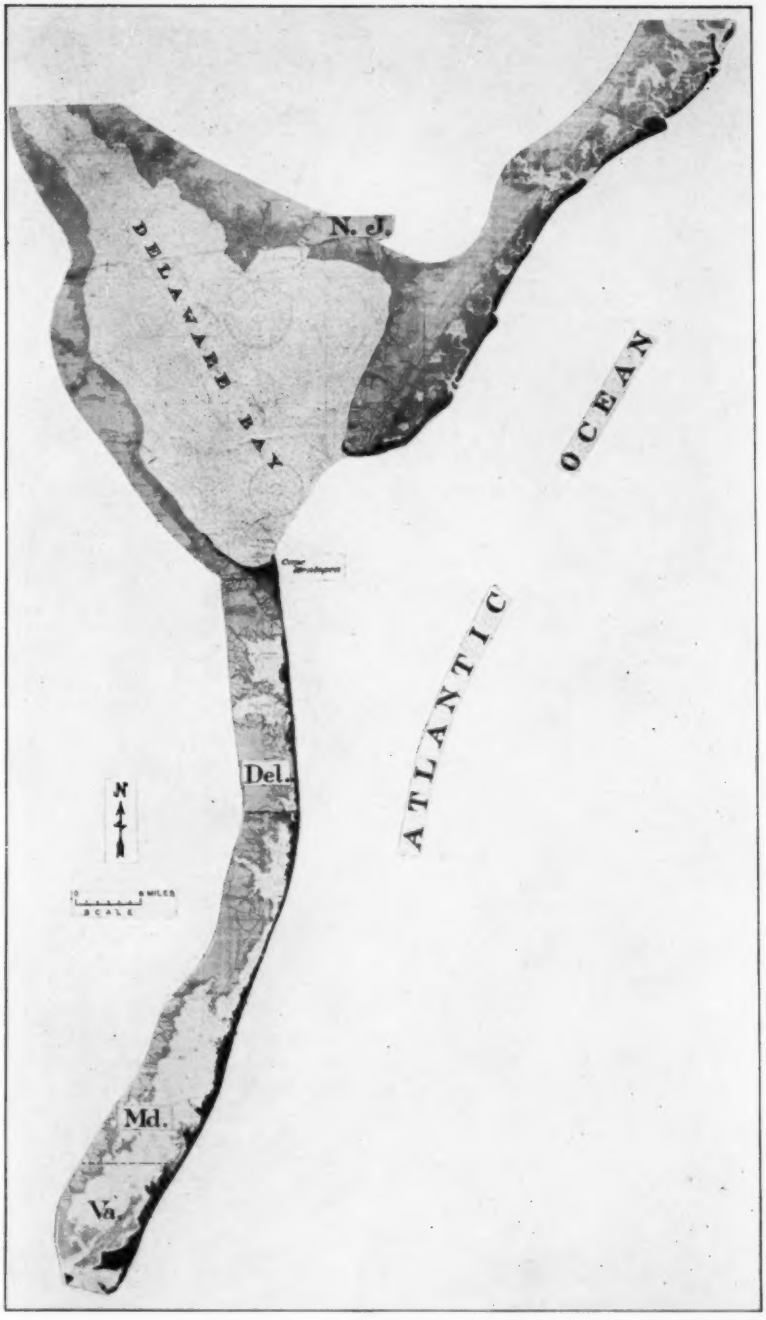

FIG. 3.—Photograph of United States Coast and Geodetic Survey's charts of the Atlantic coast of parts of New Jersey, Delaware, and Maryland. Narrow black areas along coast are offshore bars; gaps between bars are tidal inlets; shaded areas on landward side of bars are marshes; and irregular-shaped light areas within marshes are lagoons and thoroughfares of open water.

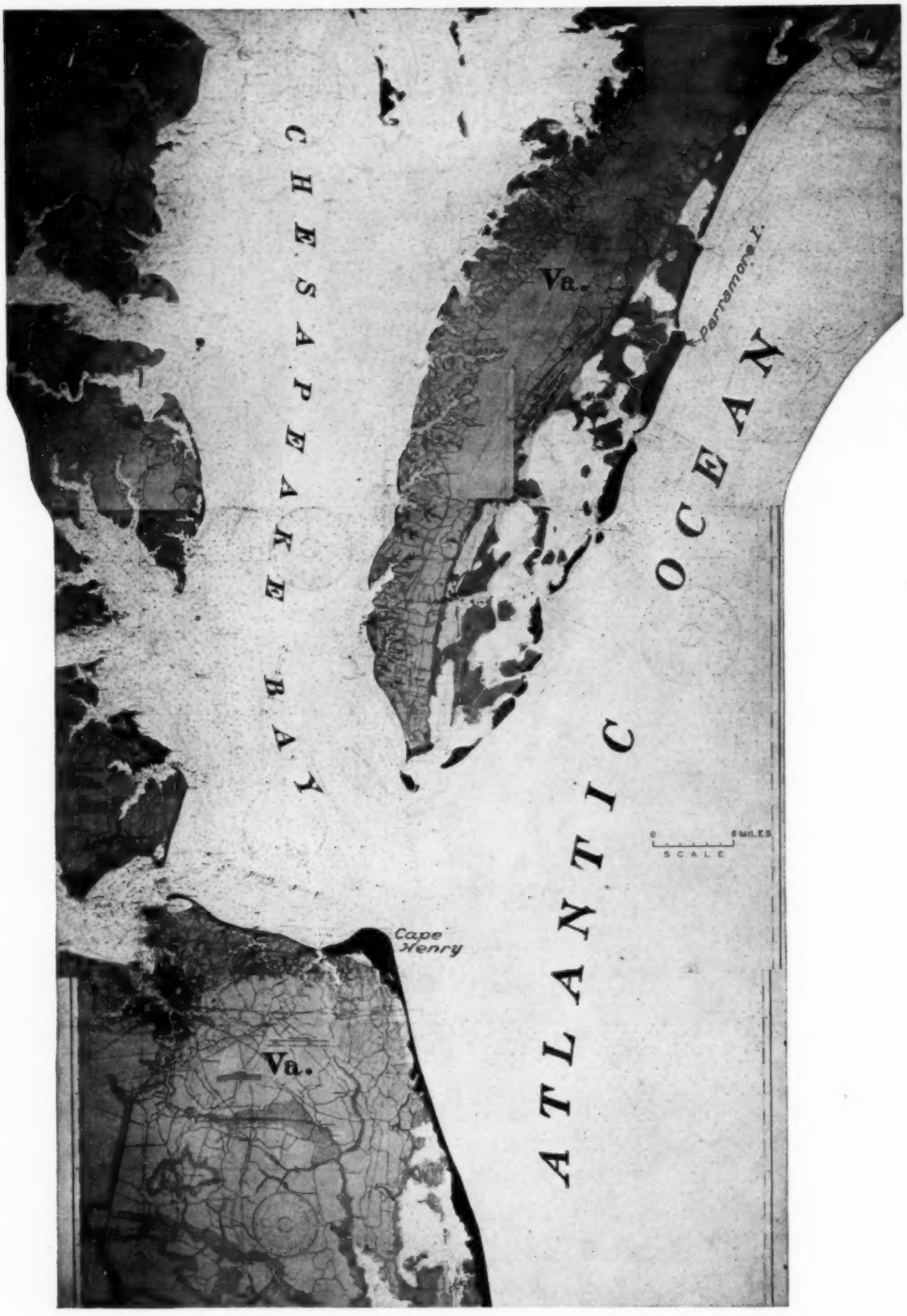

FIG. 4.—Photograph of United States Coast and Geodetic Survey's charts of the Atlantic coast of parts of Virginia. Narrow black areas along coast are offshore bars; gaps between bars are tidal inlets; shaded areas on landward side of bars are marshes; and irregular-shaped light areas within marshes are lagoons and thoroughfares of open water.

the west shore of the Dismal Swamp, in southern Virginia and northern North Carolina.

Very recently the Bluejacket sandstone, shown in Figure 7, has been studied by the writers at numerous localities between Inola, Oklahoma, and Columbus, Kansas. Inasmuch as the Bluejacket sandstone appears to be approximately equivalent to a part of the Bartlesville sand, characteristics revealed by it on the outcrops are believed to be significant in the interpretation of the buried sand bodies.

Drill cuttings of the Bartlesville and Burbank sands from about 700 wells in the area shown in Figure 1 and from a few localities in Washington and Nowata counties, Oklahoma, and cores of the sands in the Madison, Edwards Extension, and Quincy oil fields in Greenwood County, the Haverhill field in Butler County, and the Rainbow Bend field in Cowley County, Kansas, and the Burbank, South Burbank, Pershing, and Avant oil fields in Osage county and the Coodys Bluff, Delaware Childers, and Alluwe oil fields in Nowata County, Oklahoma, were examined microscopically, chiefly by Miss Leatherock, in 1934 and 1935. The microscopic study included also examination of outcrop samples from the Moberly, Warrensburg, and Aurora channel sandstones of Missouri and the Bluejacket sandstone in southeastern Kansas and northeastern Oklahoma. Samples of beach sands from the barrier beaches in Virginia, North Carolina, and Texas and from the Pleistocene beaches in the vicinity of the Dismal Swamp of Virginia were examined microscopically, and comparisons were made with the channel sandstones of Missouri and the Bartlesville and Burbank sands from wells in Kansas and Oklahoma. More than 140 thin sections, made from cores of sand from producing wells and from the outcrop samples, were studied with a petrographic microscope. The details of the microscopic study are described by Miss Leatherock[13] in a separate paper, but the general results of her study are incorporated here.

STRATIGRAPHIC POSITION OF SHOESTRING SANDS

The shoestring-sand bodies of eastern Osage County, Oklahoma, and the southeasternmost part of Kansas belong to the Bartlesville sand in the Cherokee shale, and those of western Osage County and eastern Kay County, Oklahoma, and Cowley, Greenwood, and Butler counties, Kansas, belong to the Burbank sand, which is 50–100 feet stratigraphically above the horizon of the Bartlesville sand. The Red Fork sand of southern and southeastern Osage County, Oklahoma,

[13] Constance Leatherock, "Physical Characteristics of Bartlesville and Burbank Sands in Northeastern Oklahoma and Southeastern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 2 (February, 1937).

appears to occur approximately at the horizon of the Burbank sand. These conclusions were derived by the preparation of several cross sections, based on well logs, across Osage County and the adjacent areas (Fig. 5) and agree with conclusions reached some years ago by Weirich,[14] McCoy,[15] Berger,[16] and others.

The Bartlesville and Burbank sands are best described as zones because the data show that each of these sands consist of a series of lenses that occur within narrowly restricted parts of the Cherokee shale. For instance, a body of sand near the southeast corner of Osage County, Oklahoma, is not believed to be the exact equivalent of the oil-bearing sand body of the Pershing oil field, in east-central Osage County, 25 miles away. However, the sand in each of these localities is called "Bartlesville" because each occurs somewhere in a zone, 150–200 feet thick, in the lower half of the Cherokee shale, which contains the Bartlesville sand near Bartlesville, the type locality. In the Greenwood-Butler-County region of Kansas the Sallyards and Lamont sand trends are believed to be somewhat younger than the Teeter and Quincy sand trends, but all are called "Burbank sand" because they occur within a narrowly restricted zone that occupies approximately the same stratigraphic position as the Burbank sand in the Burbank oil field of Oklahoma. The cross section in Figure 5 shows the true relation of the Bartlesville sand with respect to the Burbank sand but fails to show the local lenticular features that characterize each of the sands. If the scale of the section were greatly enlarged and additional wells were used, each sand would appear as a series of thick lenses separated by areas containing no sand.

Study of the Bluejacket sandstone on its outcrops in northeastern Oklahoma and southeastern Kansas and of logs of wells in Washington and Nowata counties, Oklahoma, showed its stratigraphic position to be within the Bartlesville sand. This correlation agrees with that made by Snider[17] many years ago.

DISTRIBUTION OF SHOESTRING SANDS

The areal distribution of the Burbank sand trends in Greenwood and Butler counties, Kansas (Fig. 1), and their similarity to the belts

[14] T. E. Weirich, "The Burbank Sand of Kansas and Oklahoma," *Oil Weekly*, Vol. 66, No. 10 (August 22, 1932), pp. 25–28.

[15] Alex. W. McCoy, oral communication.

———, "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (September–October, 1921), p. 561.

[16] F. C. Greene, "A Contribution to the Geology of Eastern Osage County," discussion by W. R. Berger, *ibid.*, Vol. 2 (1918), p. 123.

[17] L. C. Snider, *Petroleum and Natural Gas in Oklahoma*, The Harlow-Ratliff Company (1913), p. 46.

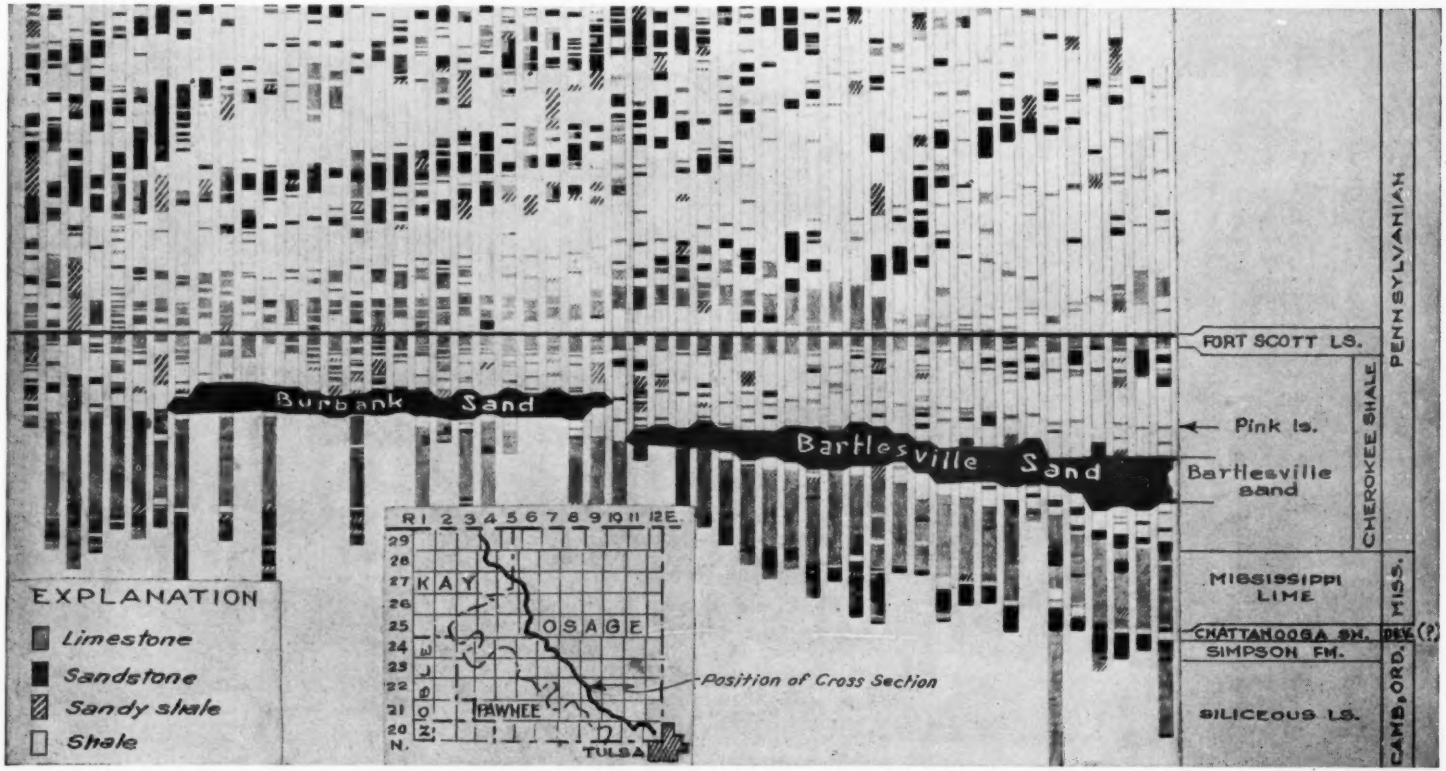

FIG. 5. Northwest-southeast geologic cross section across Osage County and part of Kay County, Oklahoma. Well logs are aligned on top of Fort Scott limestone (Oswego lime).

of offshore bars on modern coasts were described in an earlier paper.[18] A sketch of the offshore bars along a part of the New Jersey coast, placed beside a sketch of the Sallyards and Lamont shoestring-sand trends, which is reproduced in Figure 10 of that paper, shows many strikingly similar features of the distribution of the shoestring-sand bodies and the modern offshore bars. Coast charts showing the offshore bars and other features of a part of the Atlantic coast are reproduced in Figures 3 and 4 of the present paper. The sand bodies of the shoestring trends and those of the modern offshore-bar systems are arranged approximately end to end in belts that have remarkably straight courses; each deviates from straight courses only by broad sweeping curves. The offshore bars of the New Jersey coast are separated by gaps known as tidal inlets; the continuity of each of the shoestring trends is likewise broken by gaps barren of thick beds of sand at the horizon of the shoestring-sand bodies.

Because the Burbank shoestring-sand trends in southern Cowley County, Kansas, and Kay and Osage counties, Oklahoma, have not been so completely revealed by wells as they have in the more fully developed area adjacent on the north, their known distribution in the southern area is less indicative of their mode of origin. The lack of data of this type is offset, however, by information concerning the shapes of the sand bodies of the Burbank, Stanley Stringer, and South Burbank fields, which are similar to those of modern offshore bars. Moreover, if hypothetical sand bodies similar to those known in Greenwood, Butler, and northern Cowley counties, Kansas, are projected across the broad area between the shoestring fields in northern Cowley County, Kansas, and the Burbank field in Oklahoma, the distribution of all these sand bodies and those of the Burbank, Stanley Stringer, and South Burbank fields harmonizes perfectly with modern coast features.

Information about the distribution of the Bartlesville sand is less definite than that for the Burbank sand, because most of the wells in eastern Osage County, Oklahoma, where the Bartlesville sand occurs, were drilled at least 20 years ago, before it was customary to distinguish sand, sandy shale, and broken sand in the well records and before it was common practice to make detailed well logs. Microscopic examinations of well cuttings has shown that sandy shale is recorded as sand at the horizon of the Bartlesville sand in some wells, and it appears reasonable to conclude that probably such records were made

[18] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1326–31.

for many wells drilled in this region many years ago. A map prepared largely by Dillard,[19] after examining all available logs of wells in Osage County, Oklahoma, shows that the Bartlesville sand is absent in many local areas between Bartlesville sand oil pools. A rapid reconnaissance of the outcrops and a study of well records appear to show that the Bluejacket sandstone, which is equivalent to a part of the Bartlesville sand, occurs as northeast and southwest elongate, lens-shaped bodies. Moreover, the oil pools in the Bartlesville sand in eastern Osage County occur as narrow, northeast-southwest elongate areas and form an areal pattern similar to that of the Burbank sand pools, except that the belts formed by the Bartlesville pools are less widely separated and the boundaries are not so sharply defined. All these facts, together with many features of the composition and physical character of the sands, suggest that the Bartlesville sand and the Bluejacket sandstone were deposited under an environment and by processes similar to those that prevailed during the deposition of the Burbank sand, but at a much earlier time.

OFFSET ARRANGEMENT OF SAND BODIES

Modern offshore bars commonly have an offset or *en échelon* arrangement that is produced by a combination of forces, the principal one of which is the action of the longshore currents,[20] which constantly move sand lengthwise of the bars and thus extend the bars by making additions at their ends. This method of growth produces an offset arrangement in the sand bars. These offset features are particularly well developed along the south shore of Long Island, where there is a westward longshore current.[21] The west ends of the bars here are being built out westward. The sand bodies in the Sallyards and Teeter trends in Greenwood and Butler counties, Kansas, have the offset relation of adjacent sand bodies remarkably well developed. With only two exceptions, the north end of each sand body is offset westward with respect to its neighboring sand body. It appears probable that the north end of the sand body of the South Burbank oil field is offset eastward with respect to the south end of the Stanley Stringer and that a narrow area essentially devoid of good sand sepa-

[19] N. W. Bass, L. E. Kennedy, W. R. Dillard, and Constance Leatherock, "Subsurface Geology of Osage County, Oklahoma," *U. S. Dept. Interior Press Mem. 105368* (January, 1936), Plate 3B.

[20] D. W. Johnson, *Shore Processes and Shoreline Development* (1919), pp. 307–08, 370.

F. P. Gulliver, "Shoreline Topography," *Proc. Amer. Acad. Arts and Sci.*, Vol. 34 (1899), pp. 178–79, 234–37.

[21] D. W. Johnson, *op. cit.*, p. 370.

N. W. Bass, *op. cit.*, p. 1332, Fig. 11.

rates the two. The drilling of additional wells will disclose the true relations here.

GROWTH RIDGES IN OFFSHORE BARS AND IN OIL SANDS

Many of the offshore bars on the Atlantic coast are characterized by ridges of sand that trend parallel with the shore. In most localities the ridges are capped by dunes and are separated by long marshy strips or "slashes." These features, which are known as "growth ridges,"[22] are produced by the addition of sand to the seaward side of the bars. In other localities[23] the ocean may be destroying the offshore bars on the seaward side and pushing them landward over the marshes that lie behind the bars. Bogue Bank, on the coast of North Carolina, and Parramore Island, on the Virginia coast, illustrate offshore bars that have been extended seaward by overlapping beach deposits. An aerial photograph of Parramore Island, whose location is indicated in Figure 4, is shown in Figure 8.

Growth ridges are particularly prominent in the offshore bars that form capes near the entrance to large bays, such as Chesapeake Bay (Fig. 4) and Delaware Bay (Fig. 3). Cape Henry, Virginia, on Chesapeake Bay (Fig. 12), is a typical example of a broad bar that shows distinct growth ridges produced by growth of the bar seaward and northward into the bay mouth. Cape Henlopen, Delaware, at the mouth of Delaware Bay, was formed in a similar manner and has similar growth ridges.

The sand body of the Burbank oil field contains ridges that appear to represent growth features. On a map (Fig. 13) showing the thickness of the Burbank sand as recorded in the drillers' logs, prepared by H. B. Goodrich for the United States Geological Survey, the writers have indicated in black all areas where the sand is more than 70 feet thick. In the northernmost part of the field, where the maximum thickness of the sand does not reach 70 feet, a few areas where it is more than 60 feet thick are also shown in black. Inspection of this map shows that there are several narrow, elongate areas of thick sand, or ridges of sand, that have approximately parallel northwest courses.

[22] F. P. Gulliver, *op. cit.*, p. 183.
W. M. Davis, "Geographical Essays," edited by D. W. Johnson (1909), pp. 708–09.
D. W. Johnson, *op. cit.*, pp. 404–53.

[23] E. I. Brown, and others, "Beach Erosion at Folly Beach, South Carolina," *House Document No. 156, 74th Congress 1st Session* (1935).
W. J. Barden, "Wrightsville Beach, North Carolina," *House Document No. 218 73rd Congress 2nd Session* (1934).
F. P. Gulliver, *op. cit.*, pp. 184–85.
W. M. Davis, *op. cit.*, p. 709.
D. W. Johnson, *op. cit.*, p. 389.

They swing westward in the northern part of the field, much as the ridges on Cape Henry swing westward parallel with the south shore of Chesapeake Bay. Several dry holes that found no Burbank sand establish the fact that the sand body lenses out abruptly northward and its north margin is sharply defined. This abrupt termination of the sand body is what might be expected where strong currents surge in and out of a bay. It is comparable in this respect to the north beach of Cape Henry, which has a much steeper slope than the beaches on the Atlantic shore; the steepness presumably is caused by the strong currents that sweep in and out of the mouth of Chesapeake Bay.

In several localities on the Atlantic coast a long, narrow sand bar projects from the end of a much larger body of sand and trends away from the large body at a low angle, much as the Stanley Stringer sand body projects southeastward from the north end of the large sand body of the Burbank field (Fig. 14). A similar sand bar trends southeastward from Cape Henlopen, and a series of bars parallel with the east shore of Cape Cod (Fig. 14) almost duplicates the sand bodies of the Stanley Stringer and South Burbank fields. These long, narrow sand bars were built by the waves and currents later than the large sand bodies which they join.[24] The longshore currents sweep sand along the bars and attempt to extend the bars across the bay mouths,[25] but the currents that sweep in and out of the bays retard the extension of the bars, crowd the bars together at the bay mouths, and turn them landward up the bay shores. All these features appear to be common to the sand bodies at the bay mouths on the Atlantic coast and to the sand body of the Burbank oil field.

SHAPES OF SAND BODIES

It is well known that a stream channel when filled with sand imparts to the resulting deposit a valley-shaped base and a top that is wider than the lower part. On the other hand, an offshore bar is built on a nearly flat surface that has a slight slope seaward, and the top of the bar is convex upward; the lower part of the sand bar is wider than the upper part. Many cross sections of the sand bodies in Greenwood and Butler counties, Kansas,[26] show that the sand bodies there are bar-shaped in cross section; that is, their bases are approximately flat and their tops are convex upward. The cross sections show

[24] W. M. Davis, *op. cit.*, pp. 710–17.

[25] N. S. Shaler, "The Geological History of Harbors," *U. S. Geol. Survey 13th Ann. Rept.*, Pt. 2 (1893), p. 127.

[26] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1322–23, Figs. 4, 6, 7, and 8.

also that the sand bodies with northeast-southwest trends in Kansas were deposited on a base that sloped southeastward and that those with northwest-southeast trends were deposited on a base that sloped slightly southwestward.

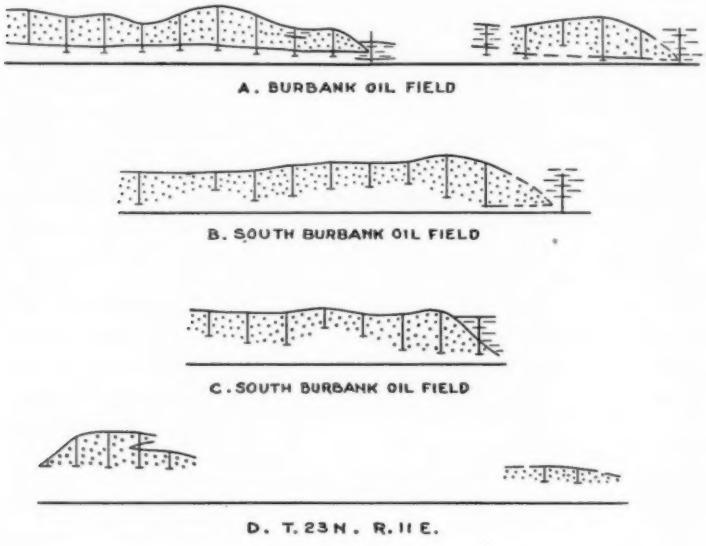

FIG. 6. Cross sections of Burbank and Bartlesville sand bodies based on well logs aligned on top of Fort Scott limestone (Oswego lime). *A*. Burbank sand in Burbank oil field and Stanley stringer, from NW. cor. of SW. ¼ of Sec. 29 east to NE. cor. of NW. ¼, SW. ¼ of Sec. 27, T. 27 N., R. 6 E. *B*. Burbank sand in South Burbank oil field, from SE. cor. of SW. ¼, NE. ¼ of Sec. 9 east to SW. cor. of NW. ¼ of Sec. 11, T. 25 N., R. 6 E. *C*. Burbank sand in South Burbank oil field, from NE. cor. of SE. ¼ of Sec. 9, east to NW. cor. of NE. ¼, SE. ¼ of Sec. 10, T. 25 N., R. 6 E. *D*. Bartlesville sand from center of SW. ¼ east to center of W. ½, SE. ¼ of Sec. 8, thence southeast to north line of SE. ¼, SW. ¼ of Sec. 16, T. 23 N., R. 11 E.

Many cross sections, one of which is shown in Figure 6, were made from logs of wells in the eastern part of the Burbank oil field and in

the Stanley Stringer, which forms the easternmost part of the Burbank field in Osage County, Oklahoma, aligned with respect to the top of the Fort Scott limestone. The cross sections show that the upper part of the sand body of the main Burbank field is narrower than the lower part and that it thins toward the eastern margin of the field; they show also that the sand lens of the Stanley Stringer is shaped like an offshore bar. It is particularly significant that most of the cross sections show that the base of the Burbank sand occurs at an increasingly greater interval below the Fort Scott limestone from west to east across the oil field. Therefore, if it is assumed that the top of the Fort Scott limestone formed a horizontal plane when deposited, it is logical to conclude that the Burbank sand was deposited on a surface that had a low slope eastward, similar in general to the slopes of the near-shore bottoms of present seas. The original eastward slope of the sand body is one of the chief facts which indicates that the Cherokee sea lay east rather than west of the Burbank field.

Cross sections of the sand body of the South Burbank field fail to show the shape of the base of the sand, because so few well logs identify the base, but many cross sections, two of which are reproduced in Figure 6, show that the upper surface of the sand body is convex upward, like the surface of an offshore bar, that the crest of the bar is near the eastern margin of the sand body, and that the slope of the top of the sand eastward from the crest is much steeper and more abrupt than the slope westward.

Few data of this character could be compiled for the Bartlesville sand in eastern Osage County, Oklahoma, because many logs of wells outside the oil fields record the Bartlesville sand to be fully as thick there as within the oil fields. However, the data are sufficient to show that the Bartlesville sand occurs as thick lenses, many of which trend northeast-southwest. Throughout eastern Osage County east-west cross sections through Bartlesville sand oil pools show that the lower part of the sand extends farther east than the upper part, and the sand appears to occur slightly lower in the Cherokee shale in the eastern part of a given township than in the western part (Fig. 6D). This fact suggests that a Bartlesville sand body is like a Burbank sand body in that the upper part of the sand body is narrower than the lower part and the sand was probably deposited on a base that sloped eastward.

The Bluejacket sandstone, which is believed to be equivalent to a part of the Bartlesville sand, is as thick as 75 feet in places on the outcrop in northwestern Mayes County, Oklahoma, but is only 10–15 feet thick and locally absent a short distance west of the outcrop,

where the horizon of the sand has been penetrated in wells. A sandstone at least 35 feet thick, which Pierce[27] states is the Bluejacket sandstone, crops out near Columbus, Kansas, which is about 60 miles northeast of the northeastern corner of Osage County, Oklahoma. The sandstone is absent a few miles northwest of the outcrops, where beds at its horizon have been penetrated by many core-drill holes.[28] These facts indicate that the Bluejacket sandstone consists of thick northeast-southwest elongate lenses whose easternmost parts have been destroyed by erosion. The data available to the writers are insufficient to indicate the details of the shapes of the lenses in cross sections.

COMPOSITION AND PHYSICAL CHARACTER

The elongate lens-shaped shoestring-sand bodies of the Burbank and Bartlesville sands range in thickness from 25 or less to more than 150 feet. Cores and well cuttings of these sands show that in some fields the sand is composed of fairly homogeneous material throughout thicknesses of more than 50 feet. The Bartlesville and Burbank sands are not everywhere solid bodies, however, but consist of thick beds of sand separated by thin beds of shale, sandy shale, and rarely limestone. Characteristically the thicker parts of sand bodies contain fewer partings of shale and sandy shale. As a rule, sand bodies contain more partings near their margins than near their middles. A few cores showed that the thick beds of sand are locally cross-bedded at angles of 10° or less; most cores reveal horizontal beds.

Bedding planes are not discernible in many cores of the main massive parts of the sand bodies. These thick homogeneous parts of the sands, however, are locally associated with beds of finely laminated sand and sandy shale, in which the quartz, mica, and other minerals and the carbonaceous material are segregated into fine laminae that are sharply defined. The finely laminated beds appear to contain much more carbonaceous material and mica than the massive homogeneous beds.

A zone of dense siltstone or very fine-grained sandstone forms the uppermost part of the sand bodies in most localities. Sandy shale containing thin beds of coaly shale and lenticular coal beds occur immediately above the sand in many localities and are in turn commonly overlain by beds of fossiliferous limestone. The record of a core from the uppermost part of the Bartlesville sand in the Pershing oil field

[27] W. G. Pierce, Map showing Geologic Structure of Southeastern Kansas Coal Fields and the Kansas Zinc-Lead District, *U. S. Geol. Survey* (1935).

[28] W. G. Pierce, oral communication.

of east-central Osage County, Oklahoma, shown in Figure 16, is typical of the varied character of the beds that make up the sand bodies in many localities.

A clean exposure of the Bluejacket sandstone in northwestern Mayes County, Oklahoma, shows it to be composed of thick beds of

FIG. 7. Bluejacket sandstone (equivalent to part of Bartlesville sand) in SE. ¼ of Sec. 8, T. 21 N., R. 18 E., 5 miles west of Pryor, Oklahoma.

homogeneous sand containing no partings throughout a thickness of 66 feet. It is almost continuously exposed for 1,000 feet westward from this locality and in that distance thins to half its maximum thickness but maintains its massive character and homogeneous composition. Exposures elsewhere in the region reveal massive Bluejacket sandstone locally as thick as 50–60 feet. The true bedding and cross-bed-

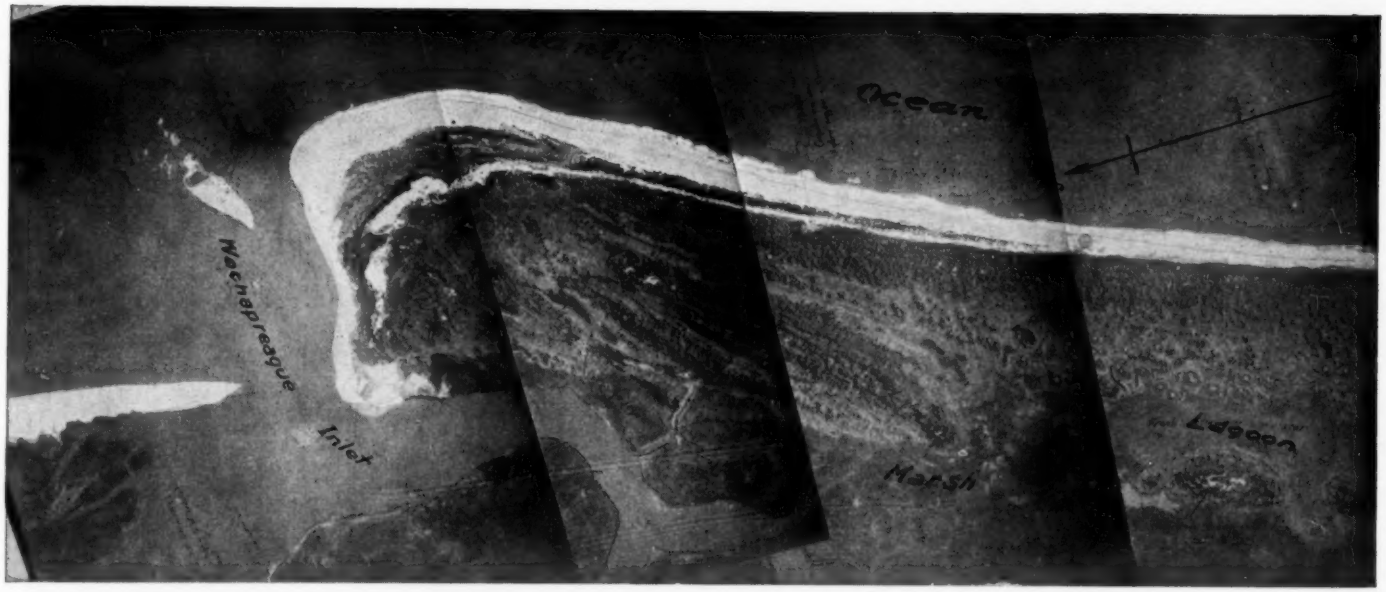

FIG. 8. Aerial photograph of northeastern part of Parramore Island, Wachapreague Inlet, and southeastern tip of Cedar Island, Virginia. (By U. S. Army Air Corps.) Beach-growth ridges are covered with vegetation and show as dark bands, some of which trend parallel with the shore and others more northeasterly than the shore. Narrow white area bordering ocean is barren sand beach.

ding seen in the outcrops of Bluejacket sandstone (Figs. 7, 9, and 11) in northeastern Oklahoma and southeastern Kansas are in general

FIG. 9. Thin-bedded Bluejacket sandstone in SE. ¼ of Sec. 8, T. 21 N., R. 18 E., 5 miles west of Pryor, Oklahoma. Angle of dip of beds is accentuated by slight slump of sandstone block.

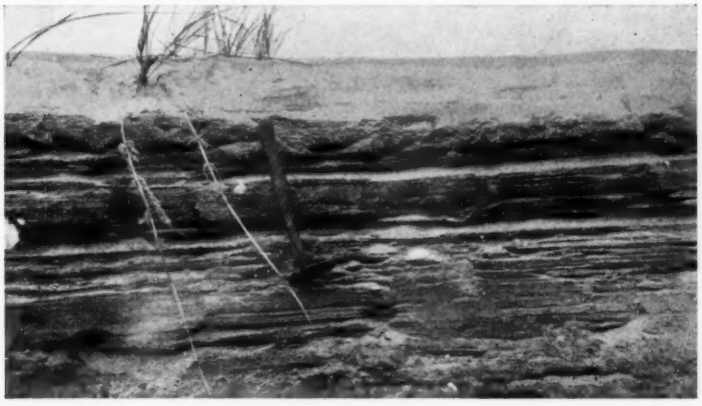

FIG. 10. Bedding in Recent offshore bar at Indian River inlet near Rehoboth Beach, Delaware.

similar to the bedding in the recently formed beach deposits on the Atlantic coast (Fig. 10).

The Bartlesville and Burbank sands are very similar in composition and physical character. They are composed mainly of quartz

grains, commonly showing new quartz growth, loosely cemented by a mixture of magnesium, iron, and calcium carbonate and locally by silica, dolomite, or calcite. In addition to quartz the sand contains about 1 per cent of mica; traces of feldspar, zircon, chlorite, glauconite, hornblende, rutile, magnetite, pyrite, and epidote; 10–20 per cent of detrital rock fragments (chert, shale, and schist), and a trace to 10 per cent of carbonaceous material. The modern beach sands are composed essentially of the same minerals that are found in the buried oil sands. Locally the oil sands contain much altered magnetite in the

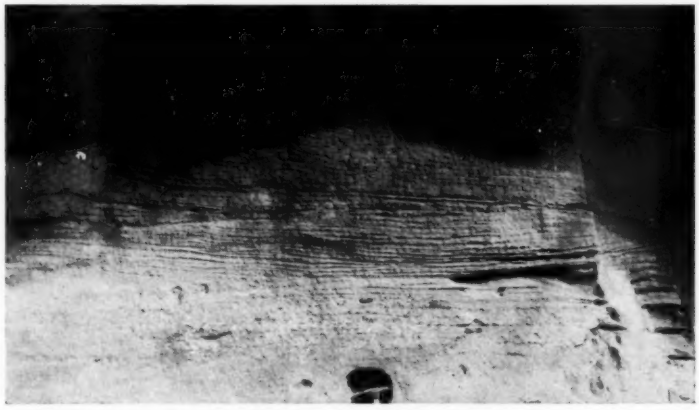

FIG. 11. Cross-bedded Bluejacket sandstone in SE. ¼ of Sec. 8, T. 21 N., R. 18 E., Oklahoma.

form of minute siderite concretions concentrated in laminae. Black sand composed mainly of ilmenite but containing magnetite is commonly concentrated in layers in the modern beach sands.[29]

The sand grains in the oil sands and in the Bluejacket sandstone are well sorted throughout the sand bodies. Recently formed beach sands are characteristically well sorted. The Bartlesville and Burbank sands in most localities are predominantly fine-grained but locally contain a large number of medium and coarse grains and a few very coarse grains. The sand in most localities contains 10 per cent of silt and clay but locally as little as 5 or as much as 40 per cent. In general the beach sands examined contained much less silt and clay than the oil sands. However, the sand from the Pleistocene beaches near the Dismal

[29] J. H. C. Martens, "Beach Sands between Charleston, South Carolina, and Miami, Florida," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 1576–80.

Swamp in Virginia contained as much silt and clay as most of the oil sands examined. Sand obtained near Wilmington, North Carolina, from the wall of a canal cut through an old offshore bar that is now surrounded by marshes, has a high content of carbonaceous material. Offshore bars along the coast of Brazil are tightly cemented with calcium carbonate, which, according to Branner,[30] was introduced into the beach sand by waters from the lagoons. These facts suggest that although many of the very fine particles that are found in the Bartlesville and Burbank sands, such as silt and clay and the finely divided carbonaceous material, probably were deposited contemporaneously with the associated coarser sand grains, some of them may have been introduced into the beach sands chemically by precipitation from percolating water and some mechanically by settling out of muddy lagoon water that filtered through the sand subsequent to its deposition.

Rounded chunks of shale were found in the Bartlesville sand in a core from the Pershing oil field in Osage County, Oklahoma, and in the Bluejacket sandstone[31] at the outcrop near Columbus, in southeastern Kansas, and have been reported from wells in the Burbank sand in Greenwood County, Kansas. Some Mid-Continent geologists[32] have suggested that the occurrence of clay balls in the oil sands is strong evidence indicating that the sands originated as stream deposits, and in support of their contention they have cited the not uncommon occurrence of clay balls in stream courses, particularly those of the semi-arid country of the western states. As pointed out by Gardner[33] and other geologists, there appears to be little doubt that some concretions found in sedimentary rocks were formed as clay balls by stream currents. According to Grabau,[34] however, "clay boulders formed of plastic clay rolled about by waves are not uncommon occurrences on the seashore" and when incorporated in sediments should have the appearance of concretions. Grabau noted the occurrence of clay boulders on the coast of Scotland and cited occurrences on the coast of the Red Sea observed by other geologists. Haas[35] described spheroidal and ellipsoidal clay balls on the beach of Lake

[30] J. C. Branner, "Stone Reefs on the Northeast Coast of Brazil," *Bull. Geol. Soc. America*, Vol. 16 (1904), pp. 1–12.

[31] Locality shown to the writers by W. G. Pierce, U. S. Geol. Survey.

[32] Oral communications.

[33] J. H. Gardner, "Physical Origin of Certain Concretions," *Jour. Geol.*, Vol. 16 (1908), pp. 452–58.

[34] A. W. Grabau, *Principles of Stratigraphy* (1924), p. 711.

[35] W. H. Haas, "Formation of Clay Balls," *Jour. Geol.*, Vol. 35, No. 2 (1927), p. 150.

Michigan. Rounded clay balls composed of the same materials as the adjacent marsh muck were observed in the beach deposits on the Atlantic coast in the course of the field work for this report. These observations indicate that clay balls may be formed in either marine or continental environments. Their occurrence in the oil sands, therefore, does not indicate necessarily that the sands were deposited by stream currents; the clay balls may have been formed by waves on beaches.

The fine and very fine sand grains and most of the medium grains in the Bartlesville and Burbank sands are angular to subangular, but the coarser grains are subrounded to rounded. These characteristics were found to prevail also in the modern beach sands that were studied. The oil-producing sand in much of the Quincy trend (Fig. 1) in Greenwood County, Kansas, is composed largely of coarse and very coarse sand grains that are rounded and subrounded. This sand[36] is coarser than sand commonly found in wind-laid deposits, and the rounded shape of the grains is much more common than generally prevails in sediment deposited by a river, but sand having these characteristics is typical of beach deposits formed by waves and currents.

A very few marine fossils were found in the shoestring sands and in thin limestone and shale beds in the sand zone, but many were found in the beds immediately above and below the sands. Broken parts of fossil shells, too fragmentary for identification, were seen in the cuttings from beds at the horizons of the Burbank and Bartlesville sands in several wells in Osage County, Oklahoma. A few fossil fragments have been observed in well cuttings from the horizon of the Burbank sand in Kansas.

It is noteworthy that so few fossils have been observed in the Bartlesville and Burbank sands. However, it is possible that shell material in considerable amount was deposited with the sand but was dissolved by the humic acids derived from the abundant organic materials associated with the sands, or that it was dissolved by rain and river water and carried away in solution or redeposited in part in the sand as cementing material. Observations on the coasts indicate that shells are being destroyed by solution not long after they become buried in the marsh. Clams and other shells were seen in abundance by Miser and Bass in the uppermost few inches of the marsh muck on the landward side of offshore bars on the coasts of Delaware and Virginia, but no shells were found in the muck below a depth of 5–6 inches. Fishermen reported that the shells that occur a few inches below the surface of the muck are "rotten and crumble in your fin-

[36] J. A. Udden, "Mechanical Composition of Clastic Sediments," *Bull. Geol. Soc. America*, Vol. 25 (1914), p. 678.

gers." It appears probable that the humic acids released by the abundant organic material in the marsh muck dissolve the calcium carbonate of the shells and thus destroy them completely soon after burial. Branner[37] described offshore bars on the coast of Brazil in which considerable shell material has been dissolved out by rain water entering the sand from above and by river water entering the sand bodies from the lagoons.

CONCLUSIONS

The shoestring-like distribution of the belts of Burbank sand in Kansas and Oklahoma, which is established by the records of thousands of wells, restricts the sand bodies to two probable types of deposits—filled stream channels or offshore bars. Less confidence can be placed in the information about the Bartlesville sand than in that available for the Burbank sand, because there are fewer exact data concerning the distribution and shapes of the Bartlesville sand bodies. Sufficient facts were learned about the Bartlesville sand, however, to justify the assertion with confidence that it and the Burbank sand were deposited by similar agencies and under similar environments, but at different times.

The areal distribution of the sand bodies in narrow, nearly straight trends, the offset arrangement of the individual sand bodies within the trends, the gaps between the sand bodies, the occurrence of features believed to represent beach-growth ridges, the probable original seaward slope of the bases of many of the sand bodies, the narrow, elongate lens-like form and the bar shape, particularly the convex top known to characterize many of the sand bodies, the composition of the sands and their physical characters, such as sorting and shapes of grains, the types of bedding, and the occurrence of marine fossils are facts that led the writers to conclude that the Bartlesville and Burbank sands were deposited as systems of offshore bars. The depositional processes and methods of preservation of the shoestring sands are described somewhat at length in a previous paper[38] and will be set forth only briefly here. The Bartlesville sand was deposited on the western shore of an arm of the Cherokee sea that occupied parts of northeastern Oklahoma and southeastern Kansas. The writers' studies corroborate McCoy's conclusions,[39] made several years ago, that

[37] J. C. Branner, "The Stone Reefs of Brazil, their Geological and Geographical Relations," *Bull. Mus. Comparative Zool.*, Vol. 44 (1904), pp. 174–76.

[38] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1333–42.

[39] Alex W. McCoy, oral communication.

for a long period of time the western shore of the shallow Cherokee sea migrated to and fro across a relatively narrow northeastward-trending strip of country in eastern Osage, Washington, and Nowata counties, Oklahoma, and in southeastern Kansas. The Bartlesville sand lenses are believed to have been deposited during this stage of the Cherokee sea as series of offshore bars. Somewhat later the Cherokee sea expanded in northeastern Oklahoma and eastern Kansas until its western shore probably trended northward across Kay County, Oklahoma, and western Cowley and Butler counties, Kansas.

The interbedded marine and non-marine sediments of the Cherokee shale indicate that the seashore migrated many times back and forth across broad areas in eastern Kansas and northeastern Oklahoma. The trends of Burbank sand bodies are believed to have been deposited as offshore bars bordering the western shore line during one of the temporary partial withdrawals of the Cherokee sea. The data in Greenwood County indicate that Burbank sand deposition represents two stages of the Cherokee sea which have been designated the Teeter-Quincy and Sallyards Lamont stages.[40]

During the time of the Teeter-Quincy stage a system of offshore bars, represented in part by the sand bodies of the Teeter and Quincy trends and probably the Haverhill trend, was slowly built along the shore.[41] On the basis of somewhat meagre data we have tentatively assigned the sand bodies of the Burbank and South Burbank fields to this stage. The close resemblance of the ridged appearance of the sand body of the Burbank field (Fig. 13) to beach-growth lines (Figs. 8 and 12) and the arrangement of the sand bodies of the Stanley Stringer and South Burbank fields with respect to the sand body of the main Burbank field (Fig. 14) led the writers to conclude that the sand bodies of these fields are deposited as a series of overlapping barrier beaches that grew progressively by additions of sand on the east side, and that the beach produced in this manner formed the south lip of the mouth of a large bay that lay north and northwest of the Burbank field (Fig. 15). It follows that the western part of the Burbank sand body is older than the eastern part, and that the sand bodies of the Stanley Stringer and South Burbank fields are still younger. To follow the analogy further, offshore bars that were formed during the Teeter-Quincy stage along the margin of the main Chero-

——— "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and Its Importance to Petroleum Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 5 (1921), pp. 559–61.

[40] N. W. Bass, *op. cit.*, pp. 1333–39, Figs. 13 and 15.

[41] *Ibid.*, p. 1333.

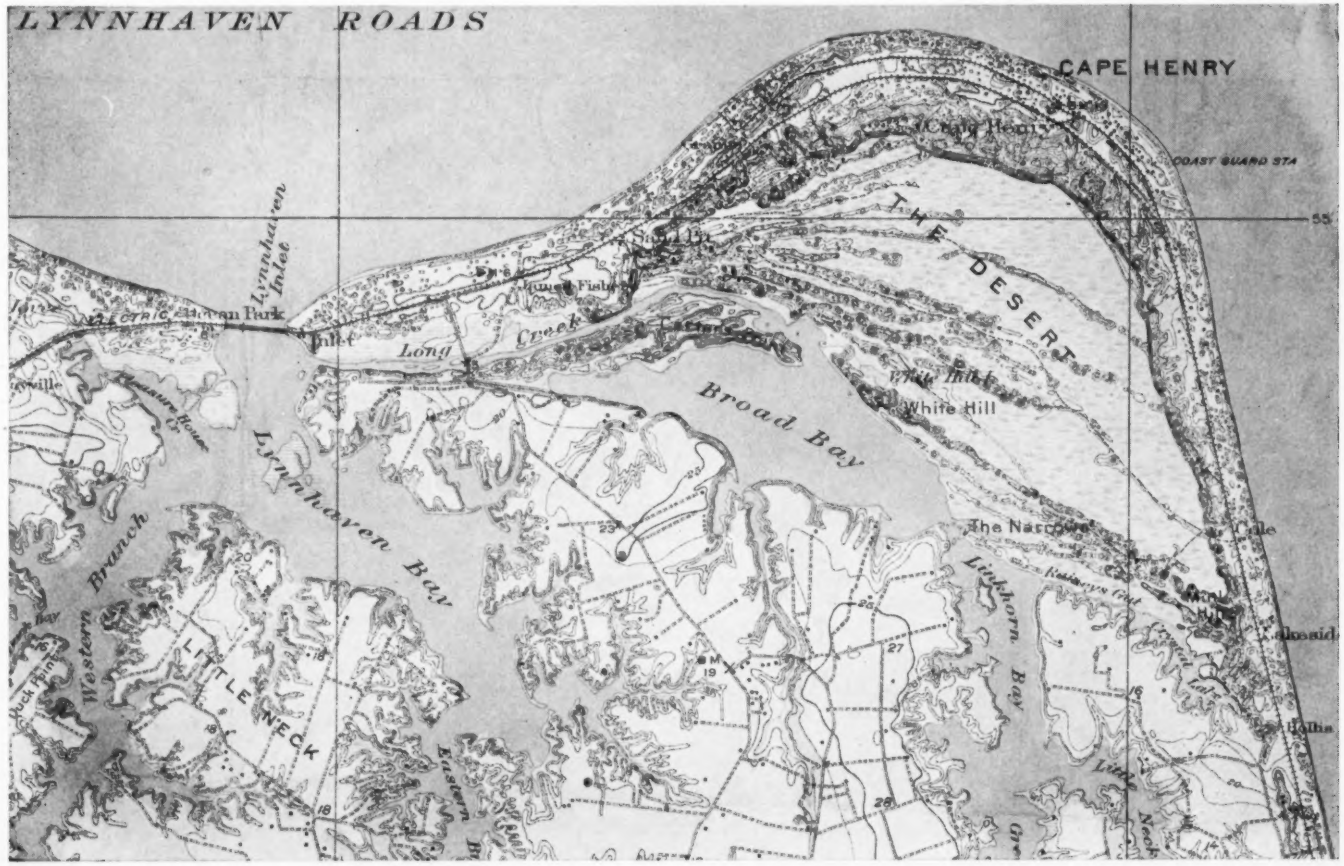

FIG. 12. Topographic map of Cape Henry, Virginia, showing ridges of sand trending approximately parallel with the shore.

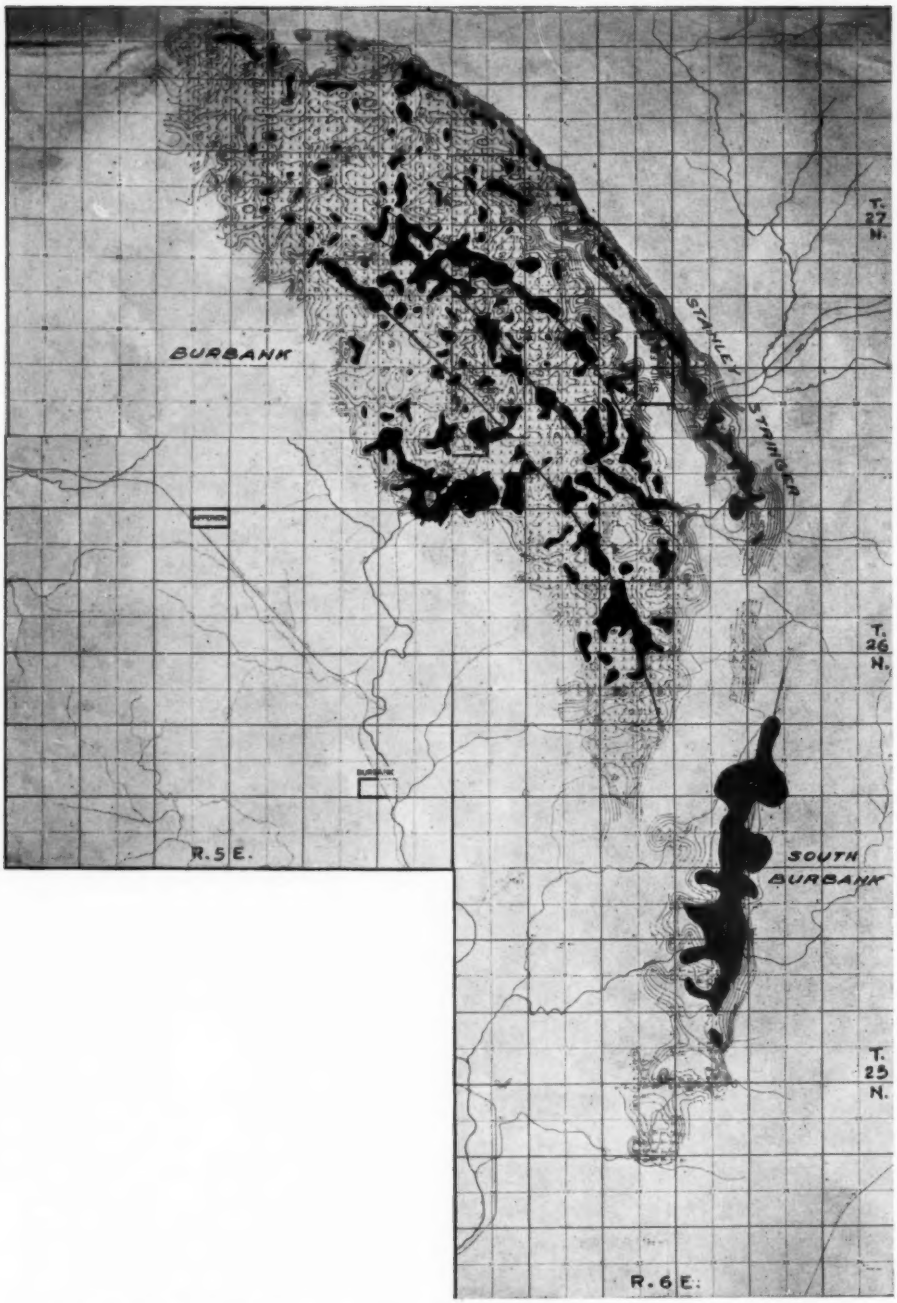

FIG. 13. Map of Burbank and South Burbank oil fields showing thickness of Burbank sand as determined from well logs. Areas where sand is thickest are shown in black. Areas of thick sand have alignments that trend approximately parallel with the east, northeast, and north margins of the sand body and are believed to represent beach-growth lines. Lines connect points of equal thickness; interval between lines is 10 feet.

kee sea northward beyond the bay mouth should be separated from the Burbank field by a strip of country, possibly several miles wide, that was occupied by the bay and may therefore be devoid of good sand bodies. The absence of Burbank sand in several dry holes in this region is therefore reasonably accounted for.

Late in the Teeter-Quincy stage the shallow areas near the margins of the sea, including the lagoons and marshes that occupied the landward side of the offshore bars, were filled with sediment consisting largely of silt, organic material, clay, and very fine sand. This silting-up process pushed the shore line slightly seaward, and the marsh sedi-

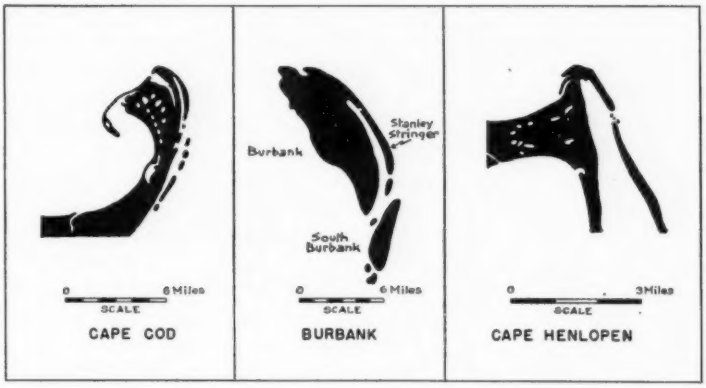

FIG. 14. Sketch maps of Cape Cod, Massachusetts, and Cape Henlopen, Delaware, showing submerged bars attached to main beach sand bodies of capes, and of sand bodies of main Burbank oil field, attached Stanley Stringer, and South Burbank oil field. Main sand bodies of Cape Cod and Cape Henlopen contain parallel ridges representing beach-growth lines.

ment encroached upon the offshore bars and buried them, at least in part. It is suggested that late in the Teeter-Quincy stage a slight subsidence of the trough of the Cherokee basin, which lay in easternmost Kansas and eastern Oklahoma,[42] accompanied by an uplift of a few feet in the Nemaha granite ridge area, which was only 10–20 miles west of the western shore line, caused an eastward tilting of much of eastern Kansas and probably northeastern Oklahoma. This slight crustal movement, together with the partial filling of the near-shore areas with sediment, shifted the western shore line of the Cherokee

[42] N. W. Bass, L. E. Kennedy, W. R. Dillard, and Constance Leatherock, "Subsurface Geology of Osage County, Oklahoma," *U. S. Dept. Interior Press Mem. 105368* (January, 1936), Pl. 1-A—"Sketch Map Showing the Thickness of the Cherokee Shale in Parts of Northeastern Oklahoma and Eastern Kansas."

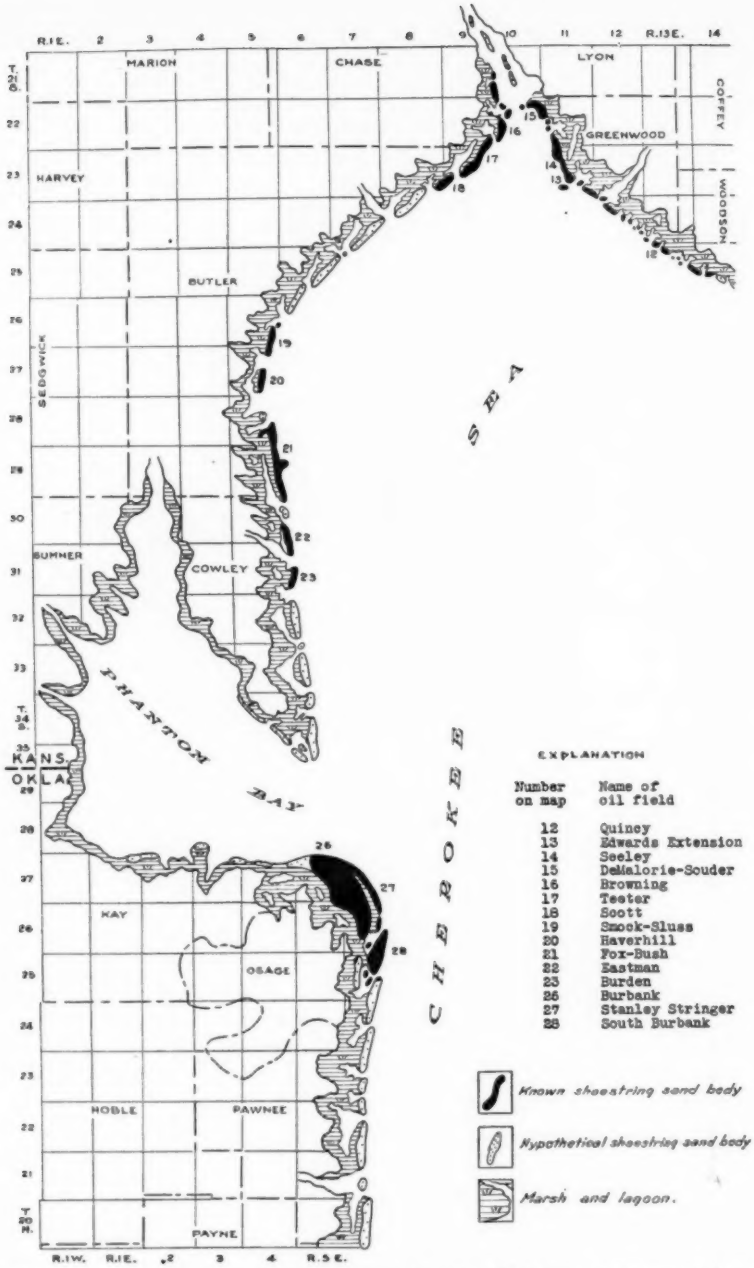

FIG. 15. Sketch of western part of Cherokee sea in parts of Oklahoma and Kansas during the Teeter-Quincy stage.

sea in Kansas a few miles eastward, but its effect in northern Oklahoma has not been determined with certainty. An elevation or depression of the shore of only a few feet would have shifted the lateral position of the shore line several miles, because the land area bordering the Cherokee sea was probably a coastal plain of extremely low relief, the sea was very shallow, and the slope of the near-shore sea bottom had a very gentle gradient. Consequently, a crustal movement of very slight magnitude would have produced the results suggested by the distribution of the shoestring-sand trends in Kansas.

As more fully described in an earlier paper,[43] the Sallyards-Lamont stage of the Cherokee sea followed the eastward shifting of the seashore lines, and during this stage the sea again built along its shore a system of offshore bars, including the sand bodies of the Sallyards and Lamont trends in Kansas (Fig. 1). The available data are insufficient to show the extension of the shore line of the Sallyards-Lamont stage into Oklahoma. A projection of the Sallyards trend (Fig. 1) of this stage southwestward through southeastern Butler County and western Cowley County, Kansas, into the Rainbow Bend field and thence nearly due south toward Oklahoma has considerable merit but involves also several serious objections. Such a scheme necessitates that the sand bodies of the Eastman and Burden fields and other sand bodies that are believed to exist in Cowley County (Fig. 15), which it appears were formed during the earlier Teeter-Quincy stage, should have remained far out at sea during the later Sallyards-Lamont stage. It seems highly probable that if left in such an environment these sand bodies would have been at least partly if not wholly destroyed by the waves and currents. The true relations of the old shore lines in southern Butler and Cowley counties, Kansas, and northern Kay and Osage counties, Oklahoma, will have to await the drilling of more wells that will reveal additional facts concerning the distribution of the sand bodies in this region.

It is truly remarkable that perishable features such as offshore bars could be preserved in such completeness as is exhibited by the belts of Burbank and Bartlesville sand bodies. The offshore bars along present-day coasts are transitory features that are modified by every storm. When the sea encroaches upon the land its waves and currents continually erode the offshore bars and drive them inland. It is probable, therefore, that an advancing sea does not create conditions conducive to the preservation of its shore features. On the other hand, if the land is being extended seaward, conditions favorable for preservation of beach deposits should be developed. There are many localities

[43] N. W. Bass, *op. cit.*, pp. 1337–39.

on the Atlantic coast of Florida,[44] North Carolina,[45] Massachusetts,[46] and elsewhere where recent offshore bars have been formed a short distance seaward from old offshore bars and have inclosed the old bars in the midst of the lagoons that lie on the landward side of the new offshore bars. One such locality is illustrated in Figure 17. The formation of the new bars extends the land seaward, and the old bars are slowly buried in the silt and organic sediment that accumulate in the lagoons. In time the old bars are completely buried. Therefore, it is

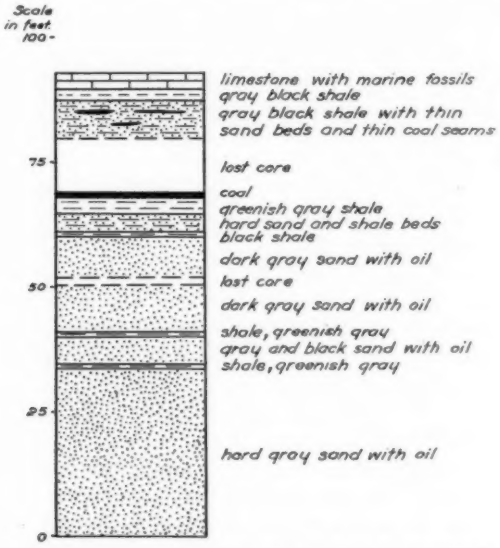

FIG. 16. Record of core from upper part of Bartlesville sand and overlying beds in Pershing oil field, Osage County, Oklahoma.

probable that the ancient Bartlesville and Burbank sand belts were buried by encroachments of the land upon the Cherokee sea in Kansas and Oklahoma rather than by deposits from an expanding sea. The dominant movement of the Cherokee sea was one of expansion upon the land, but the character of the sediments indicates that the ad-

[44] *U. S. Coast and Geodetic Survey Coast Charts 1245 and 1246.*
N. S. Shaler, "The Geological History of Harbors," *U. S. Geol. Survey 13th Ann. Rept.*, Pt. 2 (1893), p. 187.

[45] *U. S. Coast and Geodetic Survey Coast Chart 1235.*

[46] N. S. Shaler, "Sea-coast Swamps of the Eastern United States," *U. S. Geol. Survey 6th Ann. Rept.* (1885), p. 382.

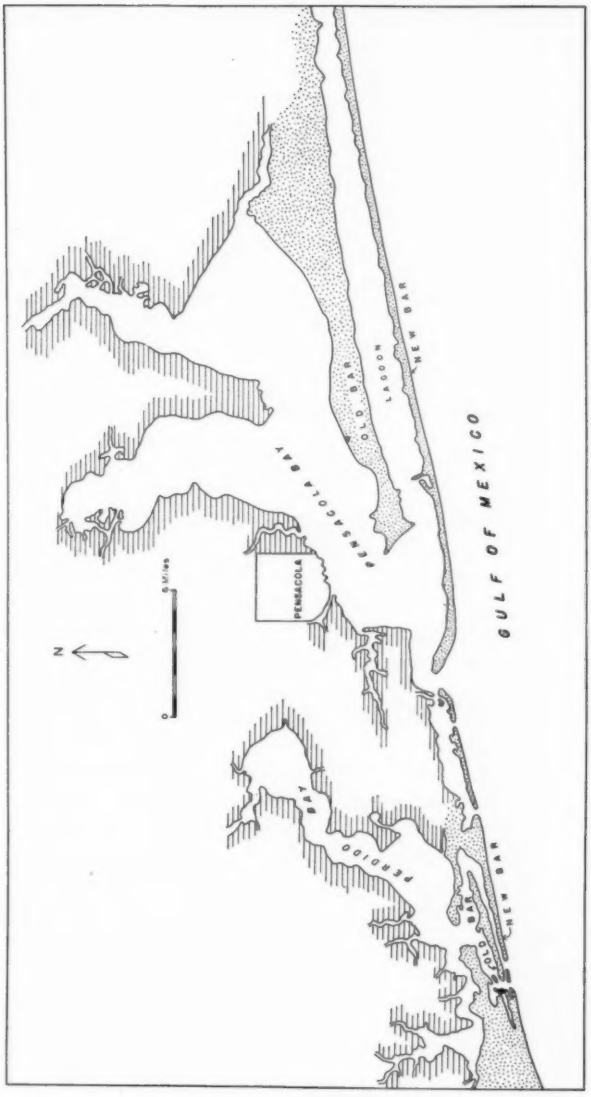

FIG. 17. Sketch of part of Gulf coast of Florida (*after U. S. Coast and Geodetic Survey Chart 1265*), showing old offshore bars inclosed by lagoons formed behind new bars.

vance was accompanied by many temporary halts and reversals. The writers believe that it was during some of these intervening periods that the Bartlesville and Burbank sands were formed and buried.

Nature's processes are seldom simple, however. The offshore bars on the Atlantic coast are in almost constant change; the ocean waves and currents erode the beaches in places and expand them in others.[47] Locally the sea pushes offshore bars landward over the marsh, exposing thick layers of marsh muck on the seashore.[48] Near-by, growth ridges on the beach prove that there the sea has recently built the beach seaward. Moreover, the processes are repeatedly reversed. Erosion will prevail for a time, and in the same locality deposition will take place at other times. Most offshore bars are being extended at one end and destroyed at the other; that is, the inlets between the bars are migrating along the coast in the direction of the longshore currents.[49]

The detailed data supplied by cores and cuttings of the Bartlesville and Burbank sands indicate that their environment of deposition was as changeable as that on the coasts of to-day. A thick zone of clean quartz sand, such as that shown in the lower part of the core record of the Bartlesville sand given in Figure 16, probably represents the middle part of an offshore bar that accumulated along a narrow strip of the coast where conditions were stable for a long time. Beds of black carbonaceous shale, which are common in the Bartlesville and Burbank sands, indicate that for short periods the marshes locally encroached upon the beaches. The occurrence of beds of sandy shale and thin beds of limestone containing marine fossils shows that for short periods the Cherokee sea spread upon the land, and that although the waves scoured the sea bottom and probably leveled off and destroyed the upper parts of the recently built offshore bars they did not destroy the bars completely. Bartlesville or Burbank sand bodies whose upper beds locally extend laterally over a broader area than the lower beds depart from the ideal bar shape, which has a wide, flat base and a narrow, convex top. A recently found example occurs in the SE. ¼ of Sec. 26, T. 26 N., R. 6 E., in the northeasternmost part of the sand body of the South Burbank field. Such a feature, if developed on the seaward side of a sand body, probably represents beach deposits formed during a minor seaward advance of the shore line, but if it is on

[47] W. J. Barden, "Wrightsville Beach, North Carolina," *Report of Beach Erosion Board, U. S. War Dept., House Document No. 218, 73rd Congress 2nd Session* (1934), Plate II.

D. W. Johnson, *op. cit.*, p. 382.

[48] W. M. Davis, "Geographical Essays," edited by D. W. Johnson (1909), p. 709.

[49] D. W. Johnson, *op. cit.* (1919), p. 374.

the landward side it records a minor advance of the beach upon the marsh. Local occurrences of thin beds of fossiliferous limestone near the margins of some of the sand bodies of Kansas and Oklahoma appear to represent deposits formed during minor advances of the sea.

The coal beds found above the sand bodies, such as are illustrated by the core record in Figure 16, indicate that as the sea built bars along its shore progressively on the seaward side the fresh-water swamps, which no doubt occupied parts of the low coastal plain, followed seaward as the coastal plain was extended, until they actually lay above the site of the earlier beach. The fossiliferous limestone shown at the top of the core represents deposition at a much later time, after the sea had again encroached far upon the land. The fossiliferous Inola limestone, which occurs above the Bartlesville sand in wells and above the Bluejacket sandstone on the outcrops, and the fossiliferous limestone beds that occur above the Burbank sand in western Osage County and may represent the Pink lime were probably deposited in this manner.

SUGGESTIONS FOR LOCATING NEW SHOESTRING-SAND OIL FIELDS

The sketch map, Figure 15, is intended to call attention to an interpretation that might be used as a guide to prospect a part of the undeveloped territory containing the Burbank sand bodies. The writers have purposely not attempted to place the hypothetical sand bodies, shown by the dotted pattern, with reference to dry holes that found sand. The map merely represents a scheme that they would greatly refine and then consider if they were to attempt to prospect the region. Figure 15 represents the coast line during the Teeter-Quincy stage of the Cherokee sea, which is the earlier of two stages of Burbank sand deposition determined by the study of the sand trends in Greenwood County, Kansas,[50] and expanded into Cowley County, Kansas, and northern Oklahoma by the writers' later work. The fact that the sand bodies of the Burbank, Stanley Stringer, and South Burbank fields have several features that are similar to those of Cape Henry, Virginia, on Chesapeake Bay, led the writers to place the large Phantom Bay north and northwest of the Burbank field, in approximately the same relative position with respect to the Burbank sand body that Chesapeake Bay holds to Cape Henry (Fig. 4). Although no facts are available that would establish the relationship of the sand bodies of the widely separated areas of northwestern Green-

[50] N. W. Bass, "Origin of Bartlesville Shoestring Sands, Greenwood and Butler Counties, Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), pp. 1326, 1333–39.

wood County and south-central Butler County, the interpretation presented in Figure 15 tentatively places the sand bodies of the Smock-Sluss, Haverhill, and other fields south of these in the same stage of deposition as the Scott, Teeter, and Browning oil fields.

The southward extension of the South Burbank trend shown in Figure 15 is probably the most attractive area for prospecting. Prospecting in central Cowley County, Kansas, in the southward extension of the trend formed by the Eastman and Burden pools, also shown in Figure 15, should discover additional oil pools. Localities such as the trend across northeastern Butler County, shown in Figure 15, and a southward projection from the Rainbow Bend field, shown in Figure 1, are obviously prospectively valuable areas for oil and gas. The sand body of the Naval Reserve oil field in west-central Osage County, Oklahoma, does not appear in Figure 15, although the expansion of the field north and south is expected. It is probable that the sand body of the Naval Reserve field was deposited at a slightly different time (possibly later) than the sand of the South Burbank field, but its exact relation to the other sand bodies is not yet known.

In conclusion, the writers would like to caution operators to prospect in a projection of an established sand trend rather than in areas to the right or left of a trend; to remember that offshore bars and the undeveloped shoestring-sand bodies commonly have an established offset arrangement, and that there are gaps in modern offshore bars and barren spots between the developed shoestring-sand bodies; and that the information disclosed by the developed oil fields overwhelmingly indicates that the shoestring-sand bodies were deposited as offshore bars and prospectors should therefore expect them to occur in systems or trends that exhibit features strikingly similar to the modern offshore bars on the Atlantic coast. Features of modern bars are admirably shown by the United States Coast and Geodetic Survey's coast charts of the Atlantic and Gulf coasts. These charts have been found exceedingly helpful in this study.

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VOL. 21, NO. 1 (JANUARY, 1937), PP. 67-79, 6 FIGS.

SANDSTONE POROSITIES IN PALEOZOIC REGION IN ARKANSAS[1]

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Little Rock, Arkansas

ABSTRACT

Porosities were determined of 98 samples of unweathered sandstones collected in the Ouachita Mountains, the Arkansas Valley, and the Ozark Plateaus of Arkansas. The average porosity in the intensely folded beds of the Ouachita Mountains was found to be 5.7 per cent, in the beds of the less folded Arkansas Valley, 7.8 per cent, and in the comparatively unfolded beds of the Ozark Plateaus, 10.9 per cent. The average degree of inclination of the folded beds in the Ouachita Mountains from incomplete figures, is estimated to be 54.1°; in the Arkansas Valley, 17.0°; and in the Ozark Plateaus, 5.1°, thus indicating the relationship between the average regional porosities of the sandstones and the average deformation of the folded beds. It appears probable that, if sufficient data were accumulated, a useful relationship could be established between the average regional porosities of the sandstones and the average regional carbon ratios of the coal in western Arkansas.

INTRODUCTION

The data set forth in this paper indicate, in a broad way, the relationship between the average regional porosity and density of the sandstones in the Paleozoic region of Arkansas and the average surface deformation of the rocks there. The relationship between the average porosities and the average carbon ratios of the coals associated with the sandstones is shown for two short north-south sections in the Arkansas Valley. These latter findings are correlated with the results obtained by Russell.[3]

INVESTIGATION

Eighty-eight samples of sandstones were collected in the Paleozoic region of Arkansas by Homer Anderson,[4] under the writer's direction. The porosities and densities were determined by the acetylene-tetrachloride method[5] by Alfred J. Holmberg.[6]

[1] Read before the Association at the Tulsa meeting, March 21, 1936. Manuscript received, October 5, 1936. Published by permission of the Arkansas Geological Survey.

[2] State geologist, Arkansas.

[3] W. L. Russell, "Porosity and Crushing Strength as Indices of Regional Alteration," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), pp. 939–52.

[4] Formerly assistant, Arkansas Geological Survey.

[5] W. L. Russell, "A Quick Method for Determining Porosity," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 931–38.

[6] University of Chicago. Tests made under the direction of Carey Croneis, department of geology.

TABLE I
DENSITY AND POROSITY DETERMINATIONS

*Specimen No.**	*Type of Sandstone*	*Density*	*Porosity*	*Inclination*	*Location by Section, Township, and Range*	*Sec.*	*T.*	*R.*
1	Jackfork	2.44	9.6	40°	SW. ¼ NE. ¼	27	2 N.	12 W.
2	Atoka	2.54	4.2	45° S.	NE. ¼	36	3 N.	13 W.
3	Atoka	2.60	0.0	Crest	NW. ¼ NW. ¼	18	3 N.	13 W.
4	Atoka	2.59	0.8	Crest	NE. ¼ NE. ¼	13	3 N.	14 W.
5	Atoka	2.40	9.1	Crest	SW. ¼ NE. ¼	30	6 N.	14 W.
6	Atoka	2.40	7.7	40° S.	NE. ¼ NE. ¼	24	6 N.	16 W.
7	Atoka	2.36	11.7	45° S.	SW. ¼	20	6 N.	16 W.
8	Atoka	2.41	8.7	Crest	Center	1	6 N.	14 W.
9	Atoka	2.44	8.2	2–10°	NW. ¼	26	7 N.	14 W.
10	Atoka	2.56	3.4	7° S.	SW. ¼	14	8 N.	14 W.
11	Atoka	2.54	4.6	1–2°	NE. ¼	28	9 N.	13 W.
12	Atoka	2.28	12.8	1–2°	NW. ¼ SE. ¼	32	10 N.	13 W.
13	Atoka	2.38	8.4	1–3°	SW. ¼	23	11 N.	14 W.
14	Atoka	2.34	10.9	1° S.	SW. ¼	3	11 N.	14 W.
15	Atoka	2.16	17.9	1° S.	SE. ¼	25	13 N.	15 W.
16	St. Peter	2.35	10.0	2°	NE. ¼	4	16 N.	15 W.
18	St. Peter	2.41	8.2	1°	NW. ¼	14	16 N.	6 W.
19	Hale	2.24	13.8	2–4°	NW. ¼ SE. ¼	28	13 N.	6 W.
20	Hale	2.28	18.1	2–4°	SW. ¼	23	12 N.	6 W.
21	Atoka	2.44	9.1	1°	NW. ¼	11	11 N.	6 W.
22	Atoka	2.42	8.2	1°	NE. ¼	34	11 N.	6 W.
23	Atoka	2.35	10.8	1°	SW. ¼	19	10 N.	5 W.
24	Atoka	2.42	7.0	1°	SW. ¼	5	9 N.	5 W.
25	Atoka	2.46	6.7	1°	SW. ¼	17	9 N.	5 W.
26	Atoka	2.45	4.5	5° S.	SW. ¼ NE. ¼	5	8 N.	5 W.
27	Atoka	2.27	12.6	4° N.	SW. ¼ SE. ¼	35	8 N.	9 W.
28	Atoka	2.43	8.4	70° N.	NW. ¼ SE. ¼	33	6 N.	12 W.
29	Batesville	2.28	13.3	1–2°	NE. ¼	19	19 N.	22 W.
30	Batesville	2.19	17.3	1–2°	NE. ¼	27	18 N.	21 W.
31	Fayetteville	2.27	14.1	2°	SE. ¼ SW. ¼	3	16 N.	20 W.
32	Atoka	2.41	9.8	1–2°	NE. ¼	3	13 N.	23 W.
33	Atoka	2.36	9.2	1–2°	SW. ¼	28	13 N.	23 W.
34	Atoka	2.22	15.8	1–2°	NE. ¼	21	12 N.	23 W.
35	Atoka	2.18	17.4	1–3°	SW. ¼	33	12 N.	23 W.
36	Atoka	2.41	8.8	1–3°	SW. ¼	10	11 N.	23 W.
37	Atoka	2.12	19.8	1–3°	N. ½	28	11 N.	33 W.
38	Hartshorne	2.43	7.3	1–3°	SW. ¼ NW. ¼	3	10 N.	23 W.
39	Hartshorne	2.40	7.9	3–6°	Center	22	10 N.	23 W.
40	Atoka	2.48	4.1	3° S.	SW. ¼ NE. ¼	34	9 N.	20 W.
41	Hartshorne	2.46	9.3	1° S.	NW. ¼ SE. ¼	28	8 N.	20 W.
42	Hartshorne	2.36	10.7	1–3°	NW. ¼ SE. ¼	16	7 N.	21 W.
43	Hartshorne	2.43	8.3	5° S.	NE. ¼	9	7 N.	22 W.
44	Atoka	2.51	5.3	7° N.	SW. ¼	14	7 N.	23 W.
45	Fort Smith	2.38	10.3	3–4°	NW. ¼	11	7 N.	24 W.
46	Atoka	2.09	20.6	Crest	SE. ¼ NW. ¼	26	7 N.	23 W.
47	Atoka	2.39	10.9	5° S.	NW. ¼	17	6 N.	22 W.
48	Atoka	2.66	0.0	Crest	NW. ¼	3	5 N.	23 W.
49	Atoka	2.54	4.0	85° S.	NE. ¼ NE. ¼	1	5 N.	23 W.
50	Atoka	2.54	3.7	30° S.	NE. ¼	12	4 N.	23 W.
51	Atoka	2.55	2.2	70° S.	S. ½	1	4 N.	23 W.
52	Atoka	2.38	10.4	5° S.	NW. ¼	13	3 N.	23 W.
53	Atoka	2.52	6.2	60° N.	NW. ¼	36	3 N.	23 W.
54	Jackfork	2.53	3.0	50–60°	NW. ¼	14	2 N.	23 W.
55	Jackfork	2.60	0.9		NE. ¼ NW. ¼	27	1 N.	25 W.

TABLE I—(*Continued*)

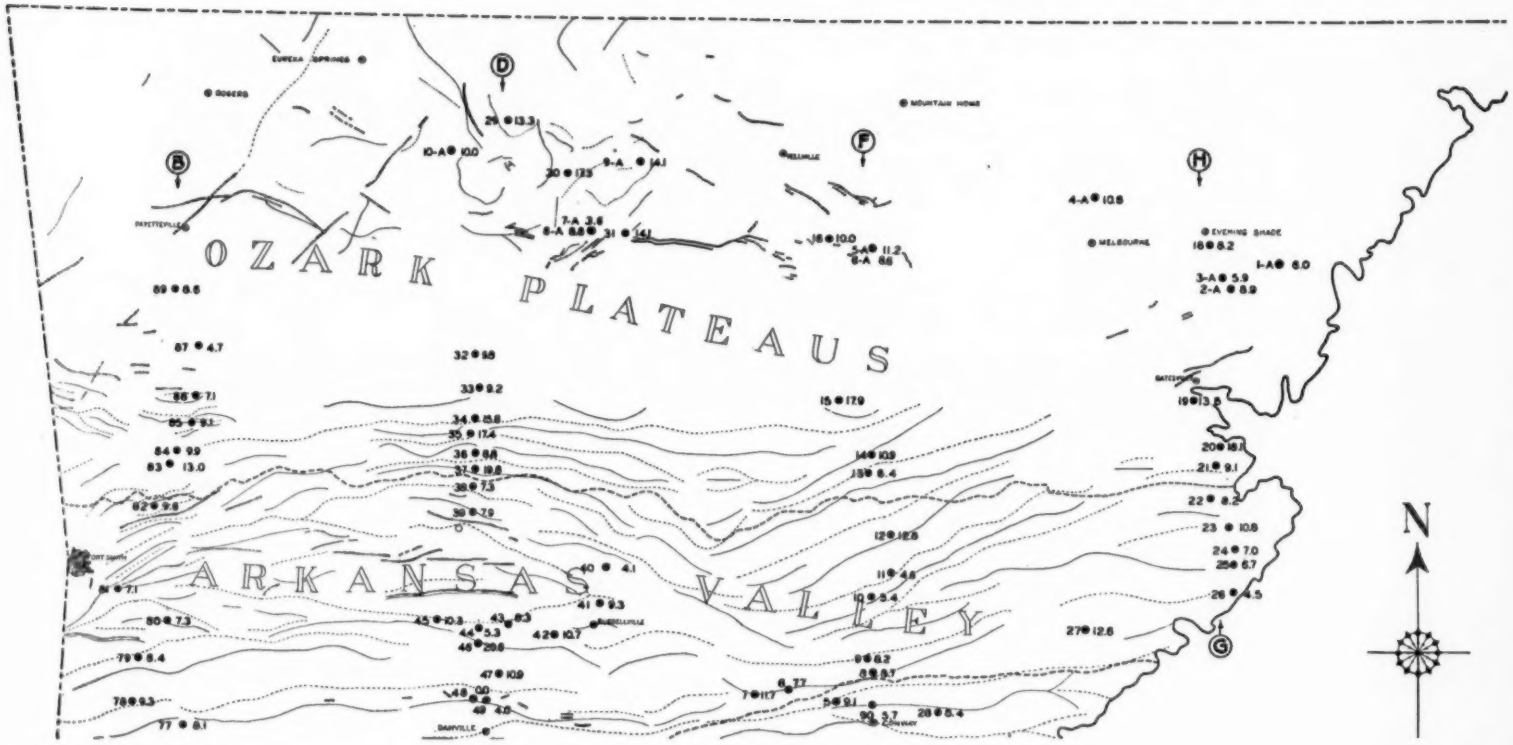
*Specimen No.**	*Type of Sandstone*	*Density*	*Porosity*	*Inclination*	*Location by Section, Township, and Range*	*Sec.*	*T.*	*R.*
56	Jackfork	2.51	5.2	Ax. syn.	NE. ¼	36	1 N.	25 W.
57	Crystal Mt.	2.19	17.5	Crest	Center	4	3 S.	25 W.
58	Blaylock	2.18	17.4		NE. ¼	19	4 S.	24 W.
59	Blaylock	2.55	2.3	Crest	SW. ¼	7	5 S.	25 W.
60	Blaylock	2.56	2.9	Crest	E. ½	9	5 S.	25 W.
61	Stanley	2.45	6.8	1–4°	NE. ¼	10	6 S.	25 W.
62	Jackfork	2.45	8.2	70° S.	NE. ¼	22	6 S.	25 W.
63	Atoka	2.48	7.4	80° N.	NE. ¼	23	7 S.	25 W.
64	Stanley	2.53	3.6	85° S.	SW. ¼	21	7 S.	31 W.
65	Stanley	2.55	3.6	70° N.	SW. ¼	31	6 S.	31 W.
66	Stanley	2.53	4.3	70° N.	SE. ¼ NW. ¼	19	6 S.	31 W.
67	Stanley	2.59	2.5	Ax. syn.	NE. ¼	7	6 S.	31 W.
68	Stanley	2.60	3.1	Crest	SW. ¼	18	5 S.	31 W.
69	Blaylock	2.46	6.6	Crest	Center	36	4 S.	32 W.
70	Jackfork	2.50	3.8	70° N.	NW. ¼	34	1 N.	30 W.
71	Atoka	2.54	4.1	70° N.	SE. ¼	24	1 N.	30 W.
72	Atoka	2.46	5.6	Crest	NE. ¼	10	1 N.	29 W.
73	Atoka	2.53	4.5	80° S.	SW. ¼	25	2 N.	29 W.
74	Atoka	2.53	5.3	Crest	SW. ¼	11	2 N.	29 W.
75	Savanna	2.50	5.4	50° N.	Cen. N½	5	3 N.	29 W.
76	Savanna	2.42	8.4	15° N.	SE. ¼	29	4 N.	29 W.
77	Atoka	2.44	8.1	3–4°	SW. ¼ NE. ¼	31	5 N.	29 W.
78	Atoka	2.41	9.3	6° S.	SW. ¼	14	5 N.	31 W.
79	Fort Smith	2.43	8.4	85–90°	SW. ¼ SW. ¼	13	6 N.	31 W.
80	Hartshorne	2.44	7.3	Crest	NW. ¼	22	7 N.	30 W.
81	Hartshorne	2.44	7.1	2–4°	NE. ¼	32	8 N.	31 W.
82	Hartshorne	2.40	9.6	2° S.	NE. ¼	31	10 N.	30 W.
83	Atoka	2.30	13.0	2–4°	NW. ¼	34	11 N.	30 W.
84	Atoka	2.36	9.9	2–4°	Cen. N. ½	22	11 N.	30 W.
85	Atoka	2.41	9.1	5–10°	NE. ¼	35	12 N.	30 W.
86	Atoka	2.49	7.0	3°	Center	13	12 N.	30 W.
87	Atoka	2.25	4.7	2°	NE. ¼	12	13 N.	30 W.
89	Fayetteville	2.44	8.6	2°	SE. ¼	32	15 N.	30 W.
90	Atoka	2.52	5.7	70° N.	SE. ¼	25	6 N.	14 W.
1-A	St. Peter	2.65	6.0		SW. of Calamine, Sharp County			
2-A	St. Peter	2.65	8.9		Near Cave City, Sharp County			
3-A	St. Peter	2.65	5.9		S. of Maxville, Sharp County			
4-A	St. Peter	2.65	10.8		Pilot Knob, Izard County			
5-A	St. Peter	2.65	11.2		Big Creek Bridge, Searcy County.			
6-A	St. Peter	2.65	8.6		Big Creek Bridge, Searcy County			
7-A	St. Peter	2.65	3.6		Marble City Falls, Newton County			
8-A	St. Peter	2.65	8.8		Marble City Falls, Newton County			
9-A	St. Peter	2.65	14.1		½ mile E. of Bellefonte, Boone County			
10-A	St. Peter	2.65	10.0		Metalton, Carroll County			

* Nos. 17 and 88 omitted.

Porosity determinations of ten specimens of St. Peter sandstone collected by A. W. Giles[7] were also made available.

Samples were taken from the three major physiographic provinces of western Arkansas—the Ouachita Mountains, the Arkansas Valley,

[7] Professor of geology, University of Arkansas. Determinations made by A. F. Melcher.


OZARK PLATEAUS
ARKANSAS VALLEY
EUREKA SPRINGS
ROGERS
FAYETTEVILLE
MOUNTAIN HOME
HELENA
MELBOURNE
EVENING SHADE
BATESVILLE
DANVILLE
CONWAY
N

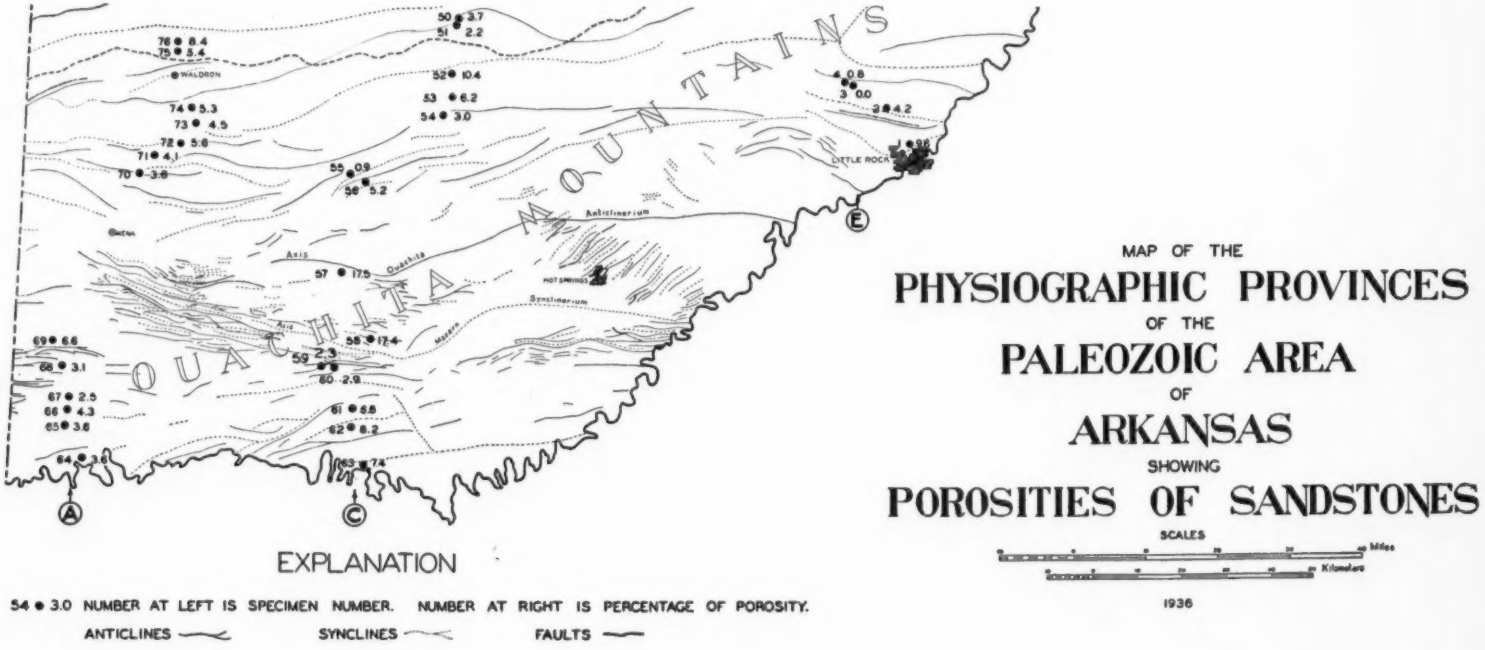


FIG. 1.—Map of physiographic provinces of Paleozoic area in Arkansas, showing porosities of sandstones.

and the Ozark Plateaus. The total area involved is 25,715 square miles distributed approximately as follows.

Area	*Square Miles*	*Percentage*
Ouachita Mountains	7,140	27.7
Arkansas Valley	6,365	24.8
Ozark Plateaus	12,210	47.5
	25,715	100.0

Every effort was made to obtain unweathered, relatively pure quartz sandstone samples, but, in many cases, this was not possible, some of the samples containing carbonates, iron oxide, and, in some cases, feldspathic minerals. The separate porosities obtained are therefore not exactly comparable.

RESULTS

Data concerning the location at which the samples were collected and their porosities and densities are shown in Table I. The same location data, the location of the axes of the principal anticlines, synclines, and faults, and the limits of the three major physiographic provinces of western Arkansas are shown graphically in Figure 1.

The porosities of the sandstone specimens collected on the four south-north routes across the Paleozoic area indicated in Figure 1 as *AB*, *CD*, *EF*, and *GH* are shown graphically in Figure 2.

The average porosities and densities of the sandstones by geological formations within the three provinces are given in Table II, and shown graphically in Figure 3.

TABLE II

Formation	*Number of Samples*	*Average Porosity*	*Average Density*	*Regional Average*	
				Porosity	*Densities*
Ouachita Mountains					
Crystal Mountain	1	17.5	2.19	5.7	2.49
Blaylock	4	7.3	2.43		
Stanley	6	3.9	2.54		
Jackfork	6	5.1	2.50		
Arkansas River Valley					
Atoka	51	8.1	2.41	7.8	2.43
Hartshorne	8	8.4	2.42		
Fort Smith	2	9.3	2.40		
Savanna	2	6.9	2.46		
Ozark Plateaus					
St. Peter	12	8.8	2.65	10.9	2.32
Batesville	2	15.3	2.23		
Fayetteville	2	11.3	2.35		
Hale	2	15.9	2.26		

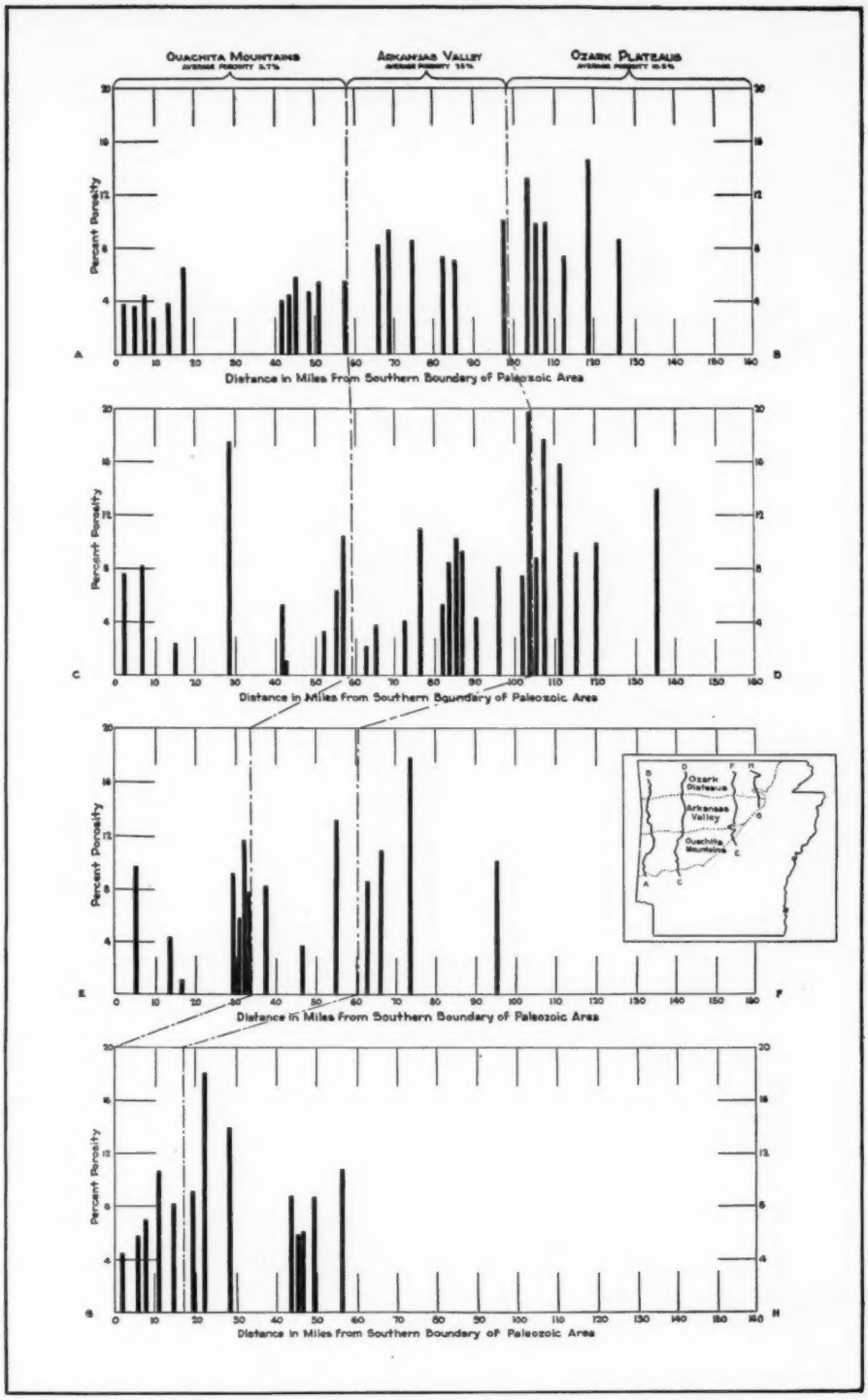


FIG. 2.—Graph showing sandstone porosities along 4 south-north routes *AB*, *CD*, *EF*, and *GH* shown in index map.

The estimated number of anticlines in the three physiographic provinces, the average inclination of the folded beds and the average

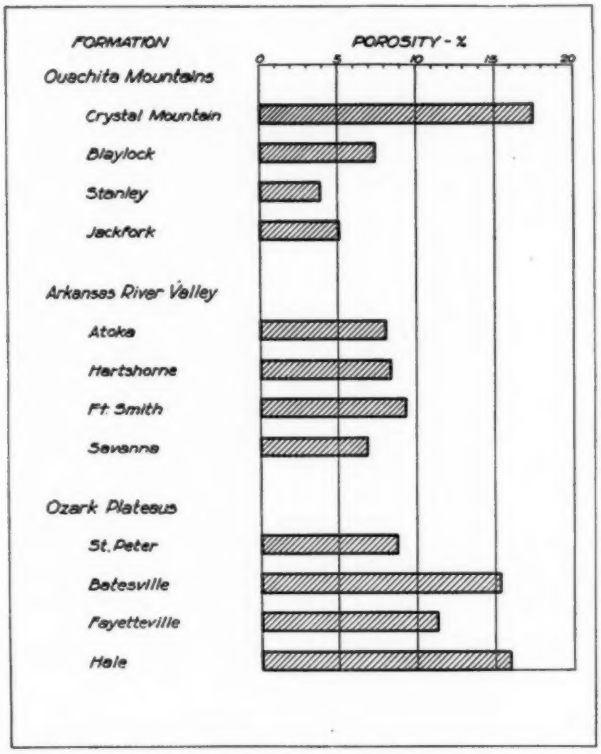


FIG. 3.—Graph showing average porosities of sandstones in formations sampled.

porosity and density of the sandstones are shown in Table III. The same data with the exception of densities are shown graphically in Figure 4.

TABLE III

Region	*Number of Anticlines*[8]	*Average dip* (°)[8]	*Average Porosity*	*Average Density*
Ouachita Mountains	53	54.1	5.7	2.49
Arkansas Valley	17	17.0	7.8	2.43
Ozark Plateaus	14	5.1	10.9	2.32

[8] Carey Croneis, "Geology of the Arkansas Paleozoic Area," *Arkansas Geol. Survey Bull. 3* (1930). Estimates made from Plates 1A and 1B.

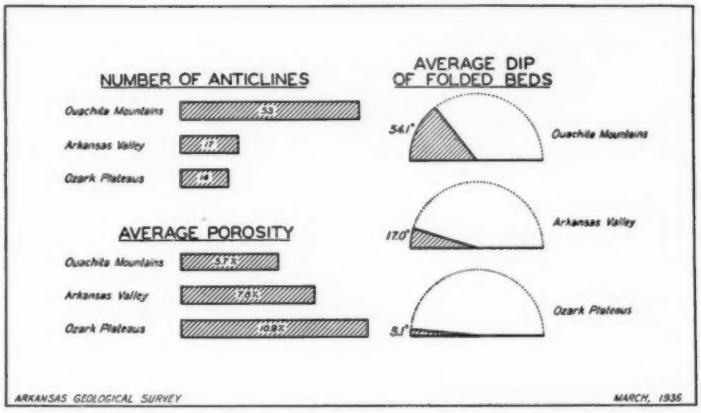


FIG. 4.—Graph showing relation of average porosities to number of anticlines and average dip of folded beds.

The average porosities of the samples collected in each physiographic province and along the lines *AB*, *CD*, *EF*, and *GH*, respectively, are shown in Table IV.

TABLE IV

Region	*Average Porosities*			
	Route AB	*Route CD*	*Route EF*	*Route GH*
Ouachita Mountains	4.6	7.3	5.4	—
Arkansas Valley	7.9	7.4	8.1	8.3
Ozark Plateaus	8.7	12.4	11.1	10.1
Average	6.5	9.1	8.1	9.3

The relationship between the porosities of Arkansas sandstone samples and the carbon ratios of associated coals and comparable values given by Russell[9] are given in Table V and shown graphically in Figure 5. Carbon ratios in Arkansas were taken from Hendricks'[10] isocarb map.

DISCUSSION OF RESULTS

Tables I, II, and III and Figures 1, 2, 3, and 4 are self-explanatory.

Table IV indicates that the porosities have a tendency to increase from west to east. It will be noted that the porosities are lowest for route *AB*, the westernmost route.

[9] W. L. Russell, *op. cit.*

[10] Thomas A. Hendricks, "Carbon Ratios in Part of Arkansas-Oklahoma Coal Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 7 (July, 1935), p. 938.

Table V and Figures 5 and 6 call for some explanation. In view of the fact that Russell[11] has shown the general relation of porosities to crushing strength in relatively pure quartz sandstone and has also indicated the general character of the relationship between these two

TABLE V

	Values Obtained	*Comparable Values of Russell*	
Line AB			
Limits of carbon ratio	75–82.5	72.5–77.5	80.0–82.5
Average of carbon ratios	78.7	—	—
Number of sandstone samples	4	10	4
Limits of porosity	7.3–9.3	3.0–9.5	1.9–3.9
Average porosity	8.3	5.4	2.7
Line CD			
Limits of carbon ratio	82.5–87.5		80.0–82.5
Average of carbon ratios	85.0		—
Number of sandstone samples	5		4
Limits of porosity	5.3–10.7		1.9–3.9
Average of porosity	8.8		2.7

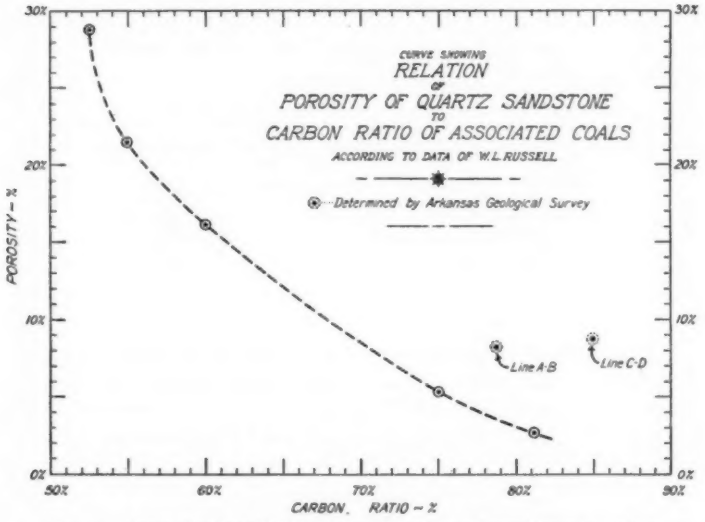


FIG. 5.—Curve showing relation of porosity of quartz sandstone to carbon ratio of associated coals (according to data of W. L. Russell).

factors, considered together, and the carbon ratios of associated coals, it would seem reasonable to assume that porosity and crushing strength have independently a more or less direct relationship to carbon ratios. To indicate the relationship of the porosities to the

[11] W. L. Russell, *op. cit.*

corresponding carbon ratios a graph (Fig. 5) has been prepared by plotting the average porosities of five of the groups of sandstones listed by Russell[12] against the arithmetical average of the carbon ratio limits of corresponding coals.

The average porosity and carbon ratio values indicated in Table V for four samples on route *AB* and five samples on route *CD* have been

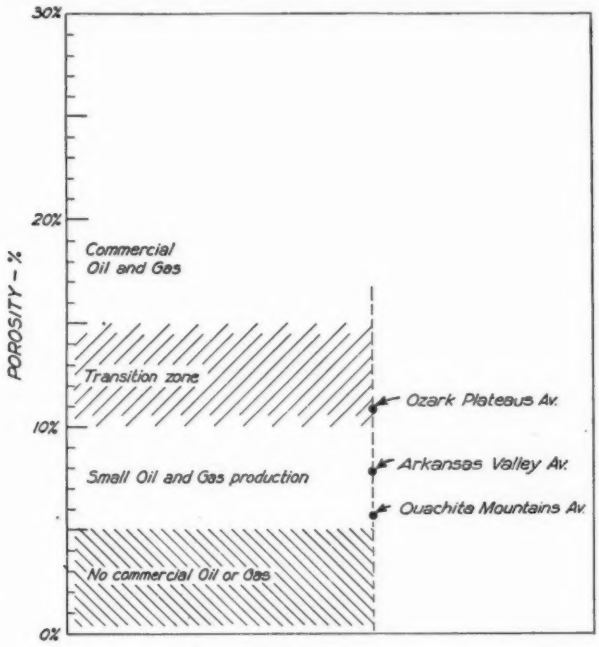


FIG. 6.—Graph showing relation of average porosities in Ozark Plateaus, Arkansas Valley, and Ouachita Mountains, to Russell's scale of porosities referred to oil and gas occurrence.

plotted on Figure 5. These two points, it will be observed, lie well above the values indicated by the curve.

As suggested by Fisher,[13] local folding probably plays an important part in local variations in metamorphic action and this may account for the fact that the Arkansas values do not agree more closely with those of the curve because the two areas for which both carbon-ratio and porosity values were obtained have been much folded. It is not

[12] W. L. Russell, *op. cit.*

[13] D. Jerome Fisher, "Carbon Ratios North of the Ouachitas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 1 (January, 1936), pp. 102–05.

possible, however, to be sure of the validity of this explanation on account of the meagerness of the available data.

The average values of the porosities determined for the three major physiographic provinces of Arkansas have been indicated on a graph (Fig. 6) together with the oil and gas possibility classifications corresponding to porosity ranges given by Russell.[14] At the present time these classifications hold fairly well for three provinces as indicated by the positions of the three points on the graph.

In connection with the oil, gas, and water reservoir capacities of the deeply buried sandstones in western Arkansas, Hendricks'[15] recent statement that "No significant increase in carbonization in coal need be expected with increased stratigraphic depth beneath the Lower Hartshorne coal" is also of much interest if it is assumed that this applies to the Pennsylvanian section in the Arkansas Valley. If this interpretation applies, it is probable that the average porosities of the sandstones there would not be expected to materially decrease with depth.

CONCLUSIONS

1. As would be expected, there is a consistent increase in the average regional porosity and decrease in average regional density of the sandstones in the Paleozoic region of Arkansas with the decrease in the average regional deformation.

2. Two general factors which probably influence sandstone porosity and density in western Arkansas are (1) regional metamorphic action indicated partly by the average deformation of the folded beds, and (2) local metamorphic action due to local deformation as indicated by the wide variations of porosity and density of the sandstones within each province.

3. There is apparently a smooth curve type of relationship between the average porosities of the sandstones and the average regional carbon ratios of the associated coals. Two values obtained add data to those published by Russell.

4. The porosity values obtained are probably fair indications of reservoir capacities for oil, gas, and ground waters of the deep-seated sandstones.

5. Further and especially detailed investigation with reference to the relation of porosity and density to local folding and to carbon ratios is desirable.

DISCUSSION

WILLIAM L. RUSSELL, Ardmore, Oklahoma: The Paleozoic region of Arkansas is one of the best areas in the United States for determining the rela-

[14] W. L. Russell, *op. cit.*

[15] Thomas A. Hendricks, *op. cit.*

tion of porosity variations to intensity of folding. Branner's paper is therefore very welcome and his investigations doubtless have an important bearing on the oil and gas prospects of the areas discussed.

In an earlier paper the writer[16] concluded that sandstone porosities are reliable indications of the intensity of regional alteration only when unweathered samples of nearly pure quartz sandstones are used. Branner states that in his investigation it was not feasible to obtain samples of this type in all cases, and his results may therefore not agree with those calculated on the basis of unweathered, pure quartz sandstone. This factor may explain some of the variations in the porosity of different formations given by Branner in Table II. In the Ouachita Mountains the Stanley sandstones, which are generally very impure and greenish gray, have a lower porosity than the sandstones from any of the other three formations given. The high (17.5) porosity of the sample of Crystal Mountain sandstone may be due to weathering and the solution of carbonates. However, the low porosity of the St. Peter sandstone, compared with the other sandstones in the same province, can scarcely be ascribed to its composition, but may be due to its greater age.

An interesting feature of Branner's paper is that the porosities of the Arkansas sandstones given in Figure 5 and Table V are much higher than the porosities of sandstones in the Appalachian region found by the writer to be associated with coals of the same carbon ratios. It may be that this condition is caused by the greater weathering of the Arkansas samples, or that the determination of a larger number of samples from the two areas would show that it is due to chance variations. On the other hand, the Arkansas sandstones may really be more porous, owing to the different geologic factors affecting them. The fact that gas production has been found in association with high carbon ratios in Arkansas, where the sandstones seem to be more porous, and not in the Appalachian region, supports this latter supposition, and suggests that sandstone porosities may be a better guide to oil and gas possibilities than carbon ratios.

The chief difficulties in using sandstone porosities to measure the degree of regional alteration are in the securing of unweathered and pure quartz sandstones, and in the abrupt and irregular variations in the porosity of even the pure quartz sandstones from the same locality. Presumably the main reliance should be placed on the nearly pure quartz sandstones, where they are present. If they are absent and the impure sandstones are used, this should be stated and allowance should be made. Obviously highly misleading results may be obtained by using weathered samples, but it is unfortunately impossible in some areas to obtain entirely unweathered sandstones from surface exposures. However, sandstones suspected of being calcareous before weathering should be discarded, for even a small amount of weathering will greatly increase their porosity. Even unweathered sandstones of pure quartz are subject to abrupt and large variations in porosity in the same locality. These variations may be produced by deposition, compaction, cementation, and solution before weathering at the surface begins. Because of these irregularities, conclusions based on a very few porosity determinations are likely to be unreliable, and averages of a large number of determinations are needed for accurate results.

[16] W. L. Russell, "Porosity and Crushing Strength as Indices of Regional Alteration," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), pp. 939–52.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 1 (JANUARY, 1937), PP. 80-96, 1 FIG.

MICRO-PALEONTOLOGIC ANALYSIS OF JACKSON EOCENE OF EASTERN MISSISSIPPI[1]

EMIL MONSOUR[2]
Baton Rouge, Louisiana

ABSTRACT

This paper is essentially a check list of the *Foraminifera* and *Ostracoda* which occur in the Garland Creek-Shubuta Bridge section of the Jackson Eocene of Clarke and Wayne counties, Mississippi, as described by the Shreveport Geological Society guide book for their eleventh annual field trip. The check list (Table I) contains an analysis of the micro-fauna of other noted Jackson localities. From the check list, the writer has attempted to show how the Jackson Eocene may be subdivided for correlation purposes. He has called attention to the fact that the upper part of the section is closely related to the Red Bluff Oligocene.

Probably more has been published on the Jackson group than on any other part of the Eocene of the Gulf Coast. Most of the papers have been generalized discussions of stratigraphy or have been devoted to a description of a part of its fossil content. The first really detailed, instrumentally measured section of the Jackson was published 2 years ago by the members of the Shreveport Geological Society.[3]

The purpose of this paper is to present a detailed micro-paleontologic analysis of the localities mentioned in this section. To aid in the interpretation of the section, the writer has included a number of samples from Frost Bridge, an excellent section exposed in northeastern Wayne County, Mississippi, and from well known Jackson localities of Louisiana, Mississippi, and Alabama.

[1] Manuscript received, October 13, 1936.

[2] Louisiana State University. Present address, Sun Oil Company, Dallas, Texas.

The writer especially wishes to express his gratitude to H. V. Howe for his kindness in placing his entire collection at the writer's disposal for study and comparison, and for his advice and assistance which proved invaluable in the preparation of this paper. The field work was done in the fall of 1935, the writer being accompanied by his brother, E. T. Monsour, and by J. W. Lea. He revisited a number of the localities in the spring of 1936, accompanied by H. V. Howe, H. N. Fisk, W. D. Chawner, and J. W. Lea. The writer wishes to acknowledge the assistance rendered by George May and Wade Hadley. Thanks are also due to F. H. Lahee and J. A. Waters, chief geologist and chief paleontologist, respectively, of the Sun Oil Company, for their aid and many helpful suggestions; and to C. L. Moody of the Ohio Oil Company for his kindly interest and assistance.

[3] Shreveport Geological Society, *Itinerary Report for Eleventh Annual Field Trip, 1934*, graphic section opposite p. 1; description, pp. 32–37.

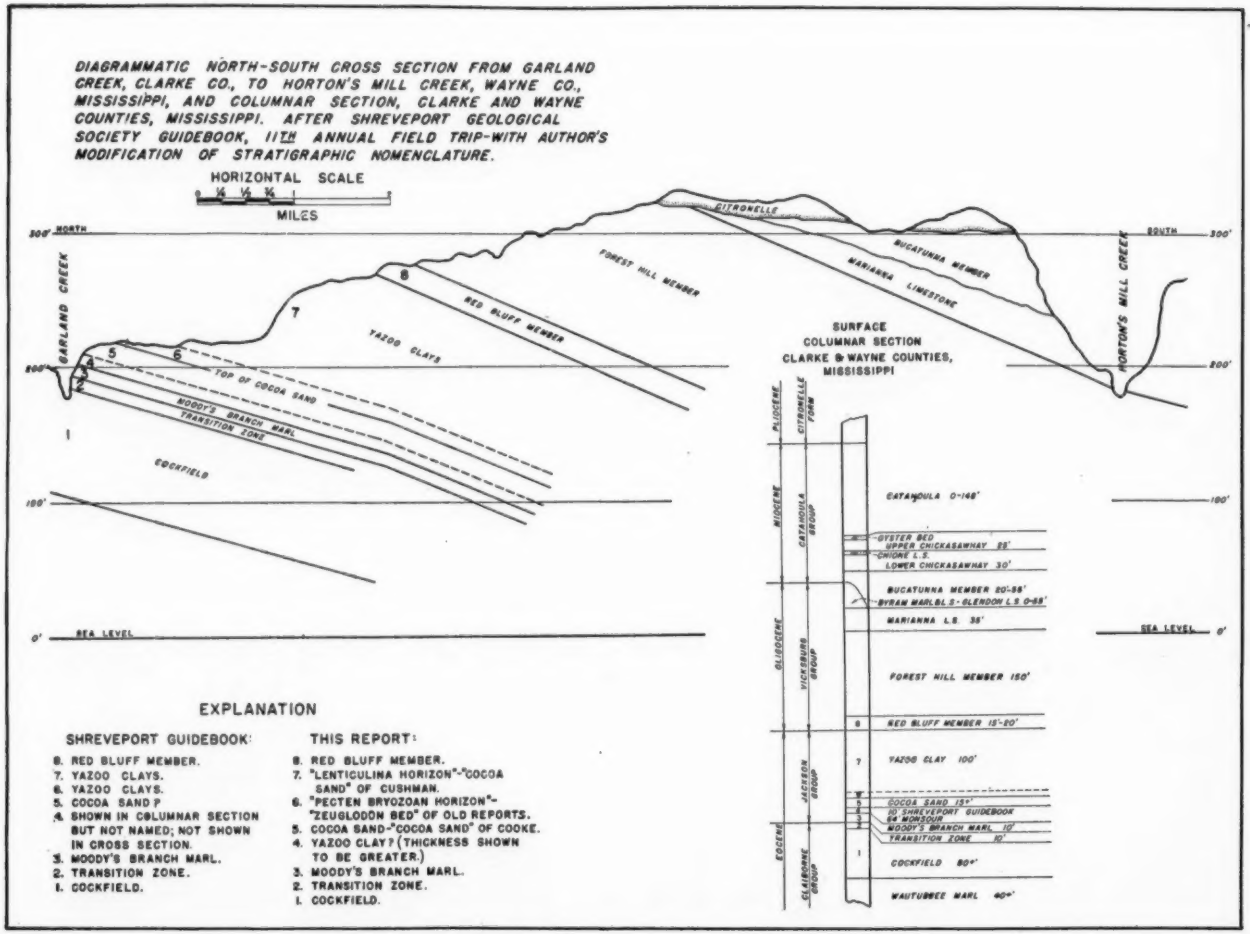


FIG. 1.—Diagrammatic cross section and columnar section, Clarke and Wayne counties, Mississippi.

TABLE I
FORAMINIFERAL CHECK LIST

Species	Locality																																	
	1					2	3		4	5	6	7						8					9						10					
	A	B	C	D	E		A	B				A	B	C	D	E		A	B	C	D	E	A	B	C	D	E		A	B				
Haplophragmoides sp.									×							×																		
Ammobaculites cf. *hockleyensis*									×																									
sp.									×	×	×					×																		
Textularia adalta		×	×	×	×				×	×	×								×						×									
broussardi								××																										
danvillensis								××																										
dibollensis			×	×	×				×	×	×							×					×	×										
dibollensis var. *humblei*																×			××						××				×					
hockleyensis var.			××		××	××	××	××	××										××						××									
mississippiensis		×	×	×	×	××	××	×	×	×	×							×	×	×	×	×	×	×	×	×	×		×	×				
mississippiensis var.												×	×	×	×	×																		
owachilaensis							×																											
recta													×	×	×	×																		
n. sp.								×																										
n. sp.														×								××			×									
n. sp.										×										×	×	×							×					
Vulvulina advena																				×						××								
Gaudryina gardnerae											×															××								
jacksonensis																				×	×	×				×××								
subquadrata																										××								
Pseudoclavulina (?) sp.																				×	×					×××	×		X?					
Karreriella n. sp. (small and inflated)																										×××								
n. sp. (small)																										×××								
n. sp. (long)										×	×									×		×				××								
Liebusella byramensis var. *turgida*											×									×	×					××	×							
Articulina terquemi											×		×	×	×					×						×	×							
Massilina decorata								×	×		×		×	×	×					×	×	×				×	×		××					
goniopleura			×	×						×	×		×	×	×								×			×	×		××	×				
jacksonensis											×			×	×																			
jacksonensis var. *punctatocostata*										×	×				×																			
pratti								×																										
n. sp.										×	×	×	×	×	×																			
n. sp.									×																									
Miliola jacksonensis										×	×	×			×																			
saxorum														×	×																			
Pyrgo inornata var. *danvillensis*								×																										

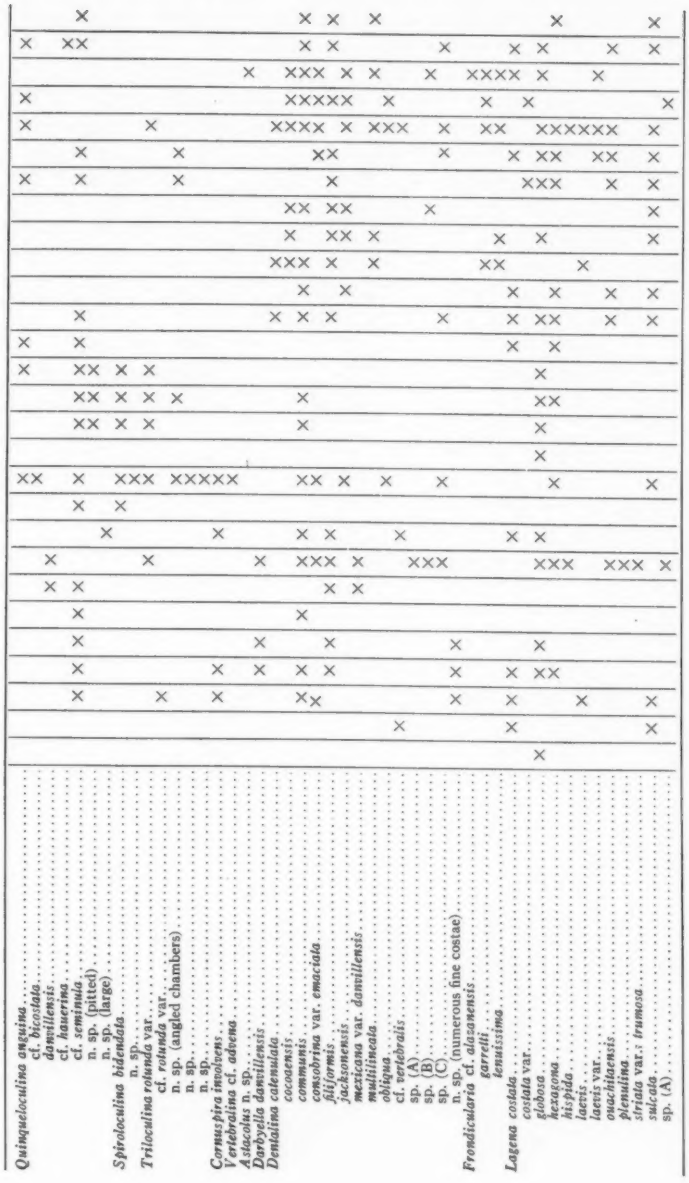

Quinqueloculina anguina
cf. bicostata
dawsillensis
cf. hauerina
cf. seminula
n. sp. (pitted)
n. sp. (large)
Spiroloculina bidendata
n. sp.
Triloculina rotunda var.
cf. rotunda var.
n. sp. (angled chambers)
n. sp.
n. sp.
Cornuspira involvens
Vertebralina cf. advena
Astacolus n. sp.
Darbyella dawsillensis
Dentalina calenulata
cocoaensis
communis
consobrina var. emaciata
filiformis
jacksonensis
mexicana var. dawsillensis
multilineata
obliqua
cf. vertebralis
sp. (A)
sp. (B)
sp. (C)
n. sp. (numerous fine costae)
Frondicularia cf. alazanensis
garretti
tensissima
Lagena costata
costata var.
globosa
hexagona
hispida
laevis
laevis var.
ovachitaensis
plenulina
striata var. trumosa
sulcata
sp. (A)

TABLE I (*Continued*)

Species	Locality																													
	1					2	3		4	5	6	7					8					9					10	
	A	B	C	D	E		A	B				A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B
sp. (B)								×																				
sp. (C)								×																				
sp. (D)								×																				
Lenticulina articulata var. *texana*				×	×	×	×	×							×		×	×	×	×	×	×	×	×	×	×		
convergens		×	×	×	×	×										×								×				
cf. *convergens*													×	×				×	×		×				×	×	×	
Marginulina cocoaensis							×	×			×							×	×	×	×				×	×		
fragaria var. *texasensis*	×	×		×	×		×	×	×		×						×	×	×	×	×	×	×	×	×			×
jacksonensis											×							×	×	×	×	×		×		×		
cf. *karreriana*																										×		
cf. *pseudohirsuta*																										×		
subrecta																			×	×	×			×	×	×		
triangularis var. *danvillensis*								×										×								×		
sp. (A)								×																				
sp. (B)							×	×																				
sp. (C)							×																					
n. sp. (beaded and longitudinally ribbed)																										×		
n. sp. (longitudinal costae)																										×		
Nodosaria cf. *cookei*																								×				
fissicostata																					×				×	×		
latejugata											×							×	×	×	×			×		×	×	
longiscata	×	×	×					×		×	×	×	×	×					×	×	×	×	×	×	×		×	×	
radicula																		×	×					×	×	×		
Planularia catahoulaensis								×																				
danvillensis								×		×	×								×	×					×	×		
ouachitaensis								×																				
n. sp.										×																		
Robulus alato-limbatus							×	×	×	×										×	×	×		×	×	×		
arcuato-striatus var. *carolinianus*		×									×								×	×	×			×	×	×		
clericii							×																					
cultratus							×	×										×						×	×	×		
(?) *danvillensis*								×																				
gutticostatus																		×	×	×	×			×	×	×		
limbosus			×	×					×			×							×	×	×			×				
limbosus var. *hockleyensis*												×										×						
mayi								×																				
Saracenaria arcuata var. *hantkeni*																					×			×		×		
danvillensis								×																				
moresiana				×	×		×	×										×	×	×	×			×	×	×		
n. sp. (beaded sutures)																			×					×	×			

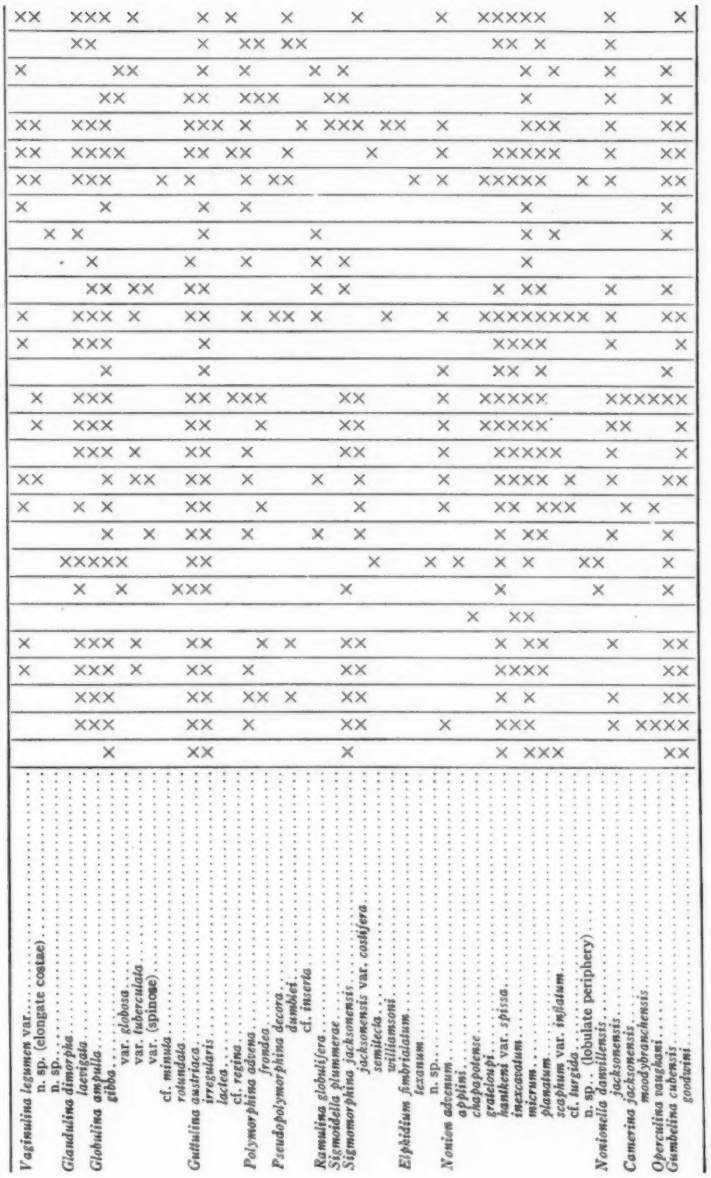

Vaginulina legumen var.
n. sp. (elongate costae)
n. sp.
Glandulina dimorpha
laevigata
Globulina ampulla
gibba
var. globosa
var. tuberculata
var. (spinose)
cf. minuta
rotundata
Guttulina austriaca
irregularis
lacta
cf. regina
Polymorphina edwina
Pseudopolymorphina decora
dumblei
cf. inaequalis
Ramulina globulifera
Sigmoidella plummerae
Sigmomorphina jacksonensis
jacksonensis var. costifera
semicincta
williamsoni
Elphidium fimbriolatum
texanum
n. sp.
Nonion advenum
applini
chapapotense
gradatum
hanleyi var. spissa
inaequale
micrum
planatum
scaphum var. inflatum
cf. largidens
n. sp. (lobulate periphery)
Nonionella dumblensis
jacksonensis
Camerina jacksonensis
moodybranchensis
Operculina tokahani
Gunbelina calcensis
goodwini

TABLE I (*Continued*)

Species	Locality																															
	1					2	3		4	5	6	7					8					9					10	
	A	B	C	D	E		A	B				A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B
Nodogenerina cooperensis																									×			
Plectofrondicularia cf. *P. vaughani*																					×				×			
n. sp.																			×	×					×	×		
Ventilabrella sp.								×																				
Hanhenina alabamaensis			×	×	×		×	×	×								×	×	×	×				×	×	×		
brevispina								×																				
danvillensis																		×							×	×		
longispina								×			×										×			×				×
mccordi								×							·													
Angulogerina danvillensis		×						×																				
ocalana										×		×	×	×	×					×	×			×	×	×		
rugoplicata																						×	×					
Bifarina vicksburgensis									×		×		×	×						×	×					×		
Bitubulogenerina mauricensis										·	×						×					×	×					×
montgomeryensis																												
Bolivina attenuata																								×				
danvillensis								×																				
gardnerae																			×	×					×	×		×
gracilis	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×	×
jacksonensis	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
mexicana var. *horizontalis*								×												×								
cf. *mexicana*		×	×	×	×					×					×						×	×	×			×		
ouachitaensis							×																					
robusta										×		×	×	×							×							
n. sp.																						×						
n. sp.						×																						
Bulimina jacksonensis							×	×										×	×	×	×	×		×	×	×		
jacksonensis var. *cuneata*																		×								×		
ovata		×	×	×	×				×		×						×	×	×	×			×	×	×	×		×
pyrula								×																				
Buliminella basistriata var. *nuda*	×	×		×	×		×	×	×		×							×		×	×			×	×	×		
elegantissima							×	×																				
cf. *elegantissima*	×	×	×							×	×		×	×	×													
n. sp.										×	×				×													
Entosolenia laevigata									×		×	×	×	×	×	×	×	×		×				×			×	×
n. sp. (long)																												
Hopkinsina danvillensis								×			×														×			
n. sp. (large)																												
(?)											×																	
Loxostoma amygdalaeformis var. *delicata*																				×						×		
dalli																			×		×				×	×		

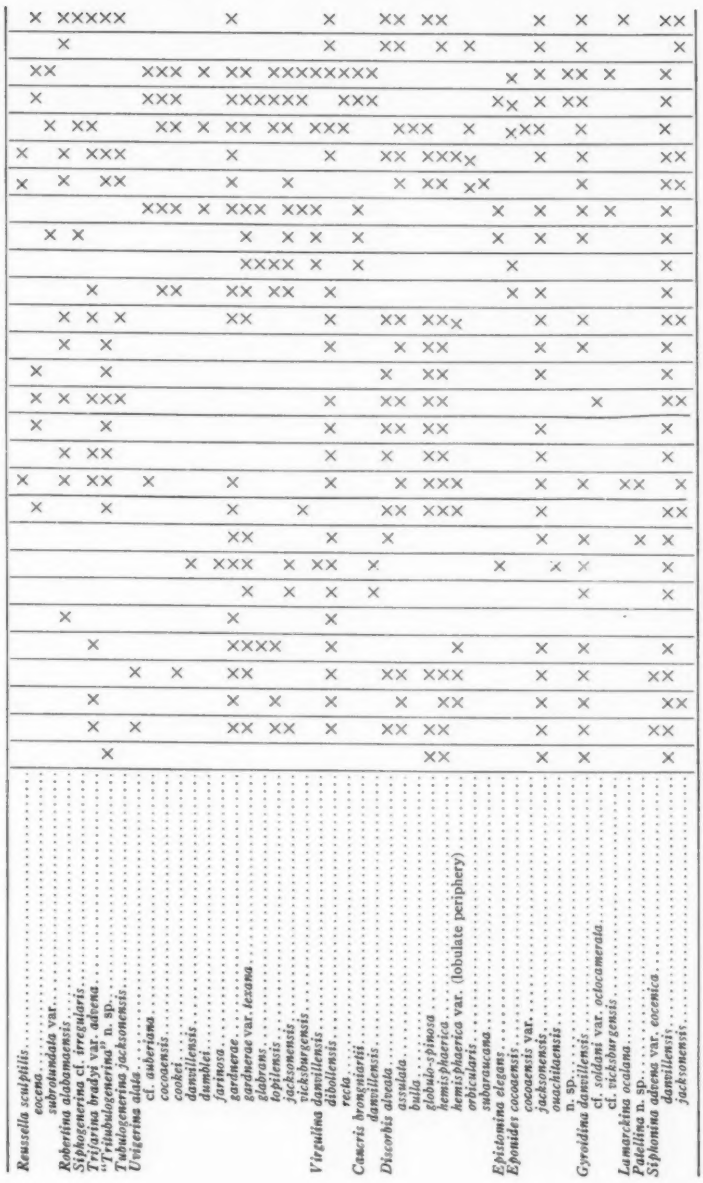

Reussella sculptilis
eocena
subrotundata var.
Robertina alabamaensis
Siphogenerina cf. irregularis
Trifarina bradyi var. advena
"Tribulogenerina" n. sp.
Tubulogenerina jacksonensis
Uvigerina alata
cf. auberiana
cocoaensis
cookei
damsilensis
dumblei
jarinosa
gardnerae
gardnerae var. texana
glabrans
lopilensis
jacksonensis
vicksburgensis
Virgulina damsilensis
diboilensis
recta
Cassris bronguiartii
damsilensis
Discorbis alveata
assulata
bulla
globulo-spinosa
hemisphaerica
hemisphaerica var. (lobulate periphery)
orbicularis
subaraucana
Epistomina elegans
Eponides cocoaensis
cocoaensis var.
jacksonensis
ouachitaensis
n. sp.
Gyroidina damsilensis
cf. soldani var. octocamerata
cf. vicksburgensis
Lamarckina ocalana
Patellina n. sp.
Siphonina advena var. eocenica
damsilensis
jacksonensis

TABLE I (*Continued*)

Species	Locality																															
	1					2	3		4	5	6	7					8					9					10	
	A	B	C	D	E		A	B				A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B
Siphoninella n. sp.											×													×				
Spirillina n. sp.											×													×		×		
Valvulineria jacksonensis																	×					×						×
texana						×	×	×																×				
Cymbaloporetta (?) *squammosa*											×		×	×								×						
var. (with spines)											×																	
Ceratobulimina sp.																				×				×				
Pulvinulinella danvillensis		×	×	×		×	×	×			×																	
cf. *eziqua*											×											×				×		
harrisi											×			×														
Cassidulina cf. *crassa*	×	×		×						×	×		×	×			×	×				×	×	×	×			×
globosa																								×		×		
inexculta											×																	
Cassidulinoides braziliensis		×	×	×	×			×	×											×	×			×	×	×		
Pullenia quinqueloba																			×	×	×			×	×	×		
n. sp.									×							×	×					×	×					
Chilostomella cylindroides							×	×																				
Globigerina bulloides	×	×	×	×	×	×	×	×			×	×	×	×	×	×	×	×			×	×	×	×	×		×	×
mexicana																						×						
ouachitaensis				×				×			×			×			×	×			×					×		
sp. (A)							×	×																				
sp. (B)		×	×	×	×	×	×	×	×	×	×						×	×	×	×	×			×	×	×		×
Globigerinoides n. sp.		×	×	×	×	×																						
Globorotalia cocoaensis		×	×	×	×	×	×	×			×		×			×		×	×	×	×		×	×	×	×		×
Anomalina cf. *bilateralis*					×	×																						
cocoaensis																				×						×		
costiana	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×		×	×	×	×	×		
acksonensis var. *texana*						×		×																				
var. (thin sutures)										×	×	×	×	×	×	×	×	×		×		×	×	×	×	×	×	×
var. (limbate sutures)	×	×	×	×	×																							
var. (large boss)						×																						
Cibicides danvillensis								×														×	×					
lobatulus	×	×							×	×	×	×	×	×	×		×	×			×	×	×	×	×	×	×	×
mississippiensis				×					×	×	×						×	×			×			×	×	×		
ouachitaensis							×	×									×		×						×			
cf. *perlucida*																										×		
yazooensis	×	×	×	×	×				×	×	×	×	×	×	×							×	×				×	
sp. (close to *pseudoungerianus*)	×	×					-		×	×	×	×	×	×	×							×	×					×
Dyocibicides danvillensis								×																				
n. sp.																								×				

Ostracodal Check List

Cytherella sp.	
Cytheridella daniellensis	
montgomeryensis	
cuneiformis	
Bythocypris (?) *globosensis*	
Bairdia sp.	
Argilloecia n. sp.	
Paracypris franquesi	
Pseudocoltonia	
Pontocypris (?) n. sp.	
Cytheridea (*Cletinocytheridea*) *caldwellensis*	
garretti	
grisbyi	
(*Haplocytheridea*) *eliersi*	
n. sp.	
montgomeryensis	
kellumi	
sp.	
sp.	
sp.	
sp.	
sp.	
Paracytheridea beliavensis	
Cythereis howardi	
montgomeryensis	
n. sp.	
Eucytheropteron spurgeonae	
Monoceratina alexanderi	
n. sp.	
Buntonia shubutaensis	
Cythereis howardi	
(?) *calahoulana*	
(?) *calahoulana* var. *pyeatti*	
dewiesni	
fortenensis	
gibsonensis	
grisbyi	
kysonensis	
Planulina cocoaensis	
mexicana	
Gypsina globula	
Discocyclina (*Discocyclina*) *floridensis*	
sp. (A)	
Lepidocyclina morloni	

TABLE I (*Continued*)

Species	Locality																													
	1					2	3		4	5	6	7					8					9					10	
	A	B	C	D	E		A	B				A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B
hysonensis var. *dohmi*			×	×					×		×		×	×			×		×	×		×	×	×	×	×	×	
(?) *israelskyi*			×	×	×	×	×		×	×	×		×					×	×			×	×	×				×
var. *morsei*				×	×	×	×	×	×																			
var. *warneri*		×	×	×	×		×	×	×	×				×		×	×	×	×			×	×				×	×
(?) *jacksonensis*		×	×	×	×		×	×	×	×	×		×	×	×		×	×	×	×	×			×		×	×	×
var. (smooth)			×		×		×	×		×	×			×													×	
var.												×		×													×	
montgomeryensis			×	×	×	×	×	×	×	×			×	×		×	×	×	×	×	×	×	×	×	×	×	×	×	×
yazooensis			×	×	×		×	×	×	×	×			×		×	×		×		×	×	×				×	×
n. sp.												×	×	×	×													
n. sp.													×		×			×						×				
Cythereis (*Pierygocythereis*) n. sp.		×																										
Cytherideis cf. *askermani*																	×											
n. sp.																	×											
n. sp.													×															
n. sp.										×			×	×			×					×	×				×	×
Cythereura n. sp.											×																	
n. sp.													×															
Loxoconcha creolensis				×						×	×	×		×	×		×	×				×	×	×				
jacksonensis			×		×		×		×	×	×		×	×	×		×	×		×	×	×	×	×		×	×	×
Cytheromorpha ouachitaensis			×	×	×			×						×			×	×				×	×	×			×	×
n. sp.																	×	×				×	×	×			×	×
Cytherella alexanderi			×	×	×		×	×	×	×	×	×	×	×	×	×	×	×				×	×	×			×	×
Brachycythere watervalleyensis		×	×	×	×		×	×	×	×	×		×	×	×	×	×	×	×	×			×	×	×	×	×	×
n. sp. (heavy carapace)												×																
n. sp.											×	×	×	×	×	×												
Eucythere lowei																		×						×				
Hemicythere n. sp.													×	×	×													
Krithe																								×				
Xestoleberis sarsi		×	×									×			×	×											×	
n. sp.												×	×			×		×				×	×			×	×	

LIST OF LOCALITIES

1. Gibson Landing on Ouachita River, Catahoula Parish, Louisiana. H. V. Howe and W. D. Chawner collection
   a. H. V. Howe Loc. 4. Transition zone, 5 feet below base of Moody's Branch marl. Elevation, 130 feet set by aneroid
   b. H. V. Howe Loc. 4 (W. D. Chawner Loc. 212). Moody's Branch marl, 100 yards downstream from road. Elevation, 130 feet (aneroid)
   c. H. V. Howe Loc. 4 (W. D. Chawner Loc. 213). Diboll zone of Yazoo clay. Elevation, 150 feet (aneroid)
   d. H. V. Howe Loc. 4 (W. D. Chawner Loc. 222). Diboll zone of Yazoo clay. Elevation, 180 feet (aneroid)
   e. H. V. Howe Loc. 4 (W. D. Chawner Loc. 211). Diboll zone of Yazoo clay. Elevation, 203 feet (aneroid), approximately 10 feet from top
2. Wyant Bluff on Ouachita River, Catahoula Parish, Louisiana. "*Textularia hockley-ensis* zone." H. V. Howe collection. At water level
3. Danville Landing, on Ouachita River, Catahoula Parish, Louisiana. (See *Louisiana Geol. Survey Bull. 2*, 1932)
   a. "Lower horizon"
   b. "Upper horizon"
4. Karl E. Young Loc. 12. Yazoo City, Mississippi, Yazoo clay of Jackson Eocene. In railway cut on Highway 49, west of town of Yazoo City, being about ¼ mile from west edge of town. Exact spot from which the sample was collected is just south of railway track and about 30 feet above mean water level of Yazoo River
5. Type lower Jackson at Belhaven College, Jackson, Mississippi. Collected by Karl E. Young, 1926
6. Type lower Jackson at junction of Town Creek and Pearl River in city of Jackson, Mississippi. Collected by Karl E. Young, 1930
7. Located approximately at SW. cor. of Sec. 28, T. 1 N., R. 16 E., Clarke County, Mississippi; in south bluff of Garland Creek, 0.2 mile east of bridge over Garland Creek. H. V. Howe collection
   a. Fossiliferous marl pockets in lignitic micaceous sands and sandy shales of "Transition zone," 6 feet below base of black shale stratum. Elevation, 188 feet
   b. Fossiliferous marl pockets in 2-foot black shale stratum. Elevation, 192 feet
   c. Moody's Branch marl. Elevation, 194 feet
   d. Fossiliferous marly limestone at top of Moody's Branch marl. Elevation, 204 feet
   e. Clay approximately 12 feet above base of Moody's Branch marl. Elevation, 206 feet
8. Starting at water level under Shubuta Bridge over Chickasawhay River; following deep gully north of Highway No. 45 eastward for a distance of 1,300 feet to top of hill. Locality is approximately along north line of the NW. ¼ of Sec. 10, T. 10 N., R. 7 W., Clarke County, Mississippi
   a. Cocoa sand (Cooke), at water's edge. Elevation, approximately 159 feet
   b. "*Pecten-Bryozoan* horizon," 16 feet above river
   c. Lower "Cocoa sand" (Cushman) or "*Lenticulina* horizon," 40 feet above river
   d. "Cocoa sand" (Cushman) or "*Lenticulina* horizon," 67 feet above river
   e. "Cocoa sand" (Cushman) or "*Lenticulina* horizon," 120 feet above river
9. Starting at water level from Frost Bridge over Bucatunna Creek, following the outcrop north of Izney-Waynesboro road westward for a distance of .6 mile, locality is approximately in the NW. ¼ of Sec. 23, T. 10 N., R. 5 W., Wayne County, Mississippi. Collected by writer
   a. Cocoa sand (Cooke), approximately 100 yards upstream from bridge and on right bank of Bucatunna Creek
   b. Cocoa sand (Cooke), approximately 150 yards upstream from bridge at bend in creek
   c. "*Pecten-Bryozoan* horizon," in lower 2 feet
   d. Lower "Cocoa sand" (Cushman) or "*Lenticulina* horizon," 2 feet below 6-inch sandstone ledge
   e. "Cocoa sand" (Cushman) or "*Lenticulina* horizon," 3 feet above 6-inch sandstone ledge
10. On "Slick" or Keyser Hill, ¼ mile west of Water Valley, Alabama. Collected by H. V. Howe. (See *Alabama Geol. Survey, Spec. Rept. 14*, 1926, pp. 274–75)
    a. Yazoo clay, 27 feet below the Cocoa sand
    b. Cocoa sand of Cooke

STRATIGRAPHIC SUMMARY

On the basis of the species enumerated, the writer believes that the Garland Creek-Shubuta Bridge section of eastern Mississippi falls naturally into three paleontologic divisions: (1) the 93 feet of clays, termed by the writer, "*Lenticulina* horizon"; (2) the "*Pecten-Bryozoan* horizon"; and (3) the lower Jackson, from the Cocoa sand to the Moody's Branch marl, including the clay bed which separates them. Furthermore, he believes that the upper part of the "*Lenticulina* horizon" may be distinguished paleontologically from the lower part, and that the "*Lenticulina* horizon" in its entirety is younger than the upper Jackson of Texas and the "Danville horizon" (upper Jackson) of Louisiana. Many characteristic species do not occur in the Jackson proper and suggest a separate stage. This fauna has been recognized by many paleontologists throughout the Caribbean region and far into South America. It is related to both the overlying Red Bluff Oligocene and the underlying typical Jackson Eocene.

The thin "*Pecten-Bryozoan* horizon" may represent all or only a part of the middle and upper Jackson of the Louisiana-Texas section.

The lower Jackson, roughly corresponding to the *Textularia dibollensis* zone of the Texas literature, consists of three distinct lithologic units, though it is paleontologically a single unit. The Moody's Branch marl, however, may be recognized by the presence of a number of species peculiar to it.

FAUNAS

No attempt is made to review the extensive literature of the Jackson group for such an undertaking would be outside the purpose of this report. The writer has, however, made a definite attempt to show the stratigraphic value of the species enumerated in the check list (Table I). To do this, he has drawn certain artificial lines within the Jackson group, these lines being determined by the appearance or disappearance of a number of easily recognized micro-fossils.

The lower Jackson of eastern Mississippi, which paleontologically appears to correspond with the old *Textularia dibollensis* zone of Cushman and Applin,[4] is divisible into three members: (1) Moody's Branch marl; (2) a clay,[5] which probably corresponds in part with the Yazoo clay; and (3) the Cocoa sand as defined by Cooke.[6]

[4] J. A. Cushman and E. R. Applin, "Texas Jackson Foraminifera," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 2 (1926), pp. 160–61.

[5] Shreveport Geological Society, *op. cit.* Unfortunately this clay body, while shown in the columnar section (opposite p. 3), was not differentiated in the graphic section published by the Shreveport Geological Society.

[6] C. W. Cooke, "Definition of Cocoa Sand Member of Jackson Formation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 11 (November, 1933), pp. 1387–88.

Species of *Foraminifera* and *Ostracoda* which start in the Moody's Branch marl (Localities 5a, 6a, and 7c) and range continuously through the Cocoa sand (Localities 8a, 9ab, and 10b) are:

Foraminifera

Textularia dibollensis Cushman and Applin
Massilina goniopleura Hadley
Triloculina n. sp. (angled chambers)
Robulus limbosus (Reuss) var. *hockleyensis* (Cushman and Applin)
Guttulina cf. *regina* (H. B. Brady, Parker, and Jones)
Bitubulogenerina mauricensis Howe
Bitubulogenerina montgomeryensis Howe
Reussella sculptilis (Cushman)
Robertina alabamensis (Cushman)
"*Tritubulogenerina*" n. sp.
Tubulogenerina jacksonensis Howe
Discorbis alveata Cushman
Discorbis hemisphaerica Cushman
Discorbis hemisphaerica Cushman var. (lobulate periphery)
Siphonina jacksonensis Cushman
Cymbaloporetta (?) *squammosa* (d'Orbigny)
Cibicides yazooensis Cushman
Cibicides sp. (close to *pseudoungerianus* Cushman)

Ostracoda

Cytheridea (*Cleithrocytheridea*) *caldwellensis* Howe and Chambers
Cytheridea (*Cleithrocytheridea*) *grigsbyi* Howe and Chambers
Cytheridea (*Haplocytheridea*) n. sp.
Eocytheropteron spurgeonae Howe and Chambers

A finer zonation is possible, however, for the following species appear to be limited to the Moody's Branch marl.

Foraminifera

Articulina terquemi Cushman
Massilina jacksonensis Cushman
Massilina jacksonsis Cushman var. *punctacostata* Cushman
Massilina n. sp.
Miliola jacksonensis Cushman
Miliola saxorum Lamarck
Quinqueloculina bicostata d'Orbigny
Quinqueloculina n. sp. (pitted)
Triloculina n. sp.
Triloculina n. sp.
Vertebralina advena Cushman
Camerina jacksonensis Gravell and Hanna
Camerina moodybranchensis Gravell and Hanna
Operculina vaughani Cushman
Cymbaloporetta (?) *squammosa* (d'Orbigny) var. (with spines)
Discocyclina flintensis (Cushman)
Discocyclina sp. (A)
Lepidocyclina mortoni Cushman

Ostracoda

Cytheridea n. sp.
Cytheridea n. sp.
Hemicythere n. sp.
Paracytheridea belhavenensis Howe and Chambers
Brachycythere n. sp.

Overlying the Cocoa sand, as defined by Cooke, are 6–10 feet of clays characterized on the surface by a profusion of pectens, oysters, large bryozoans, and shark teeth. This is apparently the horizon from

which the numerous remains of *Zeuglodon cetoides* have been obtained in previous years. An analysis of the check list appears to indicate that this "*Pecten-Bryozoan* horizon" may represent a large part of the Jackson of Louisiana and Texas which overlies the *Textularia dibollensis* zone. Species which appear for the first time in the "*Pecten-Bryozoan* horizon" at Shubuta Bridge (Locality 8b—Shreveport Geological Society, Locality JSB, Sample 2), and Frost Bridge (Locality 9c) are:

Foraminifera

Textularia dibollensis Cushman and Applin var. *humblei* Cushman and Applin
Textularia hockleyensis Cushman and Applin
Liebusella byramensis (Cushman) var. *turgida* (Cushman)
Dentalina cocoaensis (Cushman)
Frondicularia garretti Cushman
Frondicularia tenuissima Hantken
Marginulina subrecta Franke
Robulus gutticostatus (Gümbel)
Saracenaria arcuata (d'Orbigny) var. *hantkeni* Cushman
Saracenaria n. sp. (beaded sutures)
Hantkenina danvillensis Howe and Wallace
Reussella subrotundata (Cushman and Thomas) var.
Uvigerina dumblei Cushman and Applin
?Virgulina danvillensis Howe and Wallace
Virgulina recta Cushman
Eponides cocoaensis Cushman
Eponides cocoaensis Cushman var.
Valvulineria texana Cushman and Ellisor
Pullenia quinquiloba (Reuss)

Ostracoda

Monoceratina n. sp.
Eucythere lowei Howe

The following is a list of the species which have not been found to occur above the "*Pecten-Bryozoan* horizon."

Foraminifera

Textularia adalta Cushman
Textularia hockleyensis Cushman and Applin
Triloculina rotunda d'Orbigny var.
Dentalina vertebralis d'Orbigny
Lagena ouachitaensis Howe and Wallace
Lenticulina convergens (Bornemann)
Marginulina fragaria Gümbel var. *texasensis* Cushman and Applin
Planularia ouachitaensis Howe and Wallace
Sigmomorphina williamsoni (Terquem)
Nonion advenum (Cushman)
Nonion hantkeni (Cushman and Applin) var. *spissa* Cushman
Gumbelina goodwini Cushman and Jones

Ostracoda

Cytherelloidea montgomeryensis Howe
Paracypris franquesi Howe and Chambers
Cytheridea (*Cleithrocytheridea*) *garretti* Howe and Chambers
Cytheridea (*Cleithrocytheridea*) *ehlersi* Howe and Stephenson
Cytheridea (*Cleithrocytheridea*) *kellumi* Howe and Stephenson
Cytheropteron danvillensis Howe and Chambers
Monoceratina alexanderi Howe and Chambers
Monoceratina n. sp.
Cythereis broussardi Howe and Chambers
Cythereis (*?*) *catahoulana* Howe and Pyeatt

Trifarina bradyi Cushman var. *advena* Cushman
Discorbis assulata Cushman
Discorbis bulla Cushman
Discorbis globulo-spinosa Cushman
Discorbis orbicularis (Terquem)
Eponides cocoaensis Cushman var.
Valvulineria texana Cushman and Ellisor
Cythereis (?) *catahoulana* Howe and Pyeatt var. *pyealti* Howe and Chambers
Cythereis hysonensis Howe and Chambers
Cythereis (?) *israelskyi* Howe and Pyeatt var. *morsei* Howe and Pyeatt
Cythereis n. sp.
Loxoconcha creolensis Howe and Chambers
Cytheromorpha n. sp.
Cytheretta alexanderi Howe and Chambers
Eucythere lowei Howe
Krithe n. sp.

In the Shubuta Bridge section of the Shreveport Geological Society,[7] samples 3–9, inclusive, constitute the upper part of the section referred by them to the Jackson Eocene. These samples were taken from approximately 93 feet of light cream-colored, compact, calcareous clay. This clay was referred by the Shreveport Geological Society to the Yazoo clay but an examination of the check list shows that it is paleontologically quite different. The *Foraminifera* described by Cushman[8] as coming from the "Cocoa sand" of Alabama undoubtedly came from this horizon rather than from the sand bed which Cooke[9] named the Cocoa sand. These clays apparently do not possess a satisfactory formation name at the present time. In the field they may be recognized by the great abundance of large species of *Lenticulina* which may be readily detected with a hand lens. As a matter of convenience, solely, the writer refers to this horizon as the "*Lenticulina* horizon."

The upper part of the "*Lenticulina* horizon" differs somewhat paleontologically from the lower part. The following are the more diagnostic species which make their first appearance in the basal part of the "*Lenticulina* horizon" (Localities 8c and 9d).

Foraminifera

Vulvulina advena Cushman
Gaudryina jacksonensis Cushman
Nodosaria fissicostata (Gümbel)
Planularia danvillensis Howe and Wallace
Plectofrondicularia cf. *P. vaughani* Cushman
Loxostoma dalli (Cushman)
Planulina cocoaensis Cushman
Planulina mexicana Cushman

The upper part of the "*Lenticulina* horizon" is distinguished mainly by the appearance of the following species, several of which continue

[7] Shreveport Geological Society, *op. cit.*

[8] J. A. Cushman, "Eocene Foraminifera from the Cocoa Sand of Alabama," *Contrib. Cushman Lab. Foram. Research*, Vol. 1, Pt. 3, No. 16 (1935), pp. 65–70.
"Additional Foraminifera from the Upper Eocene of Alabama," *ibid.*, Vol. 4, Pt. 3, No. 64 (1928), pp. 73–79.

[9] C. W. Cooke, *op. cit.*

commonly into the overlying Red Bluff and younger horizons (Localities 8de and 9e).

Foraminifera

Pseudoclavulina n. sp.
Anomalina cocoaensis Cushman
Astacolus n. sp.
Frondicularia cf. *alazanensis* Nuttall
Marginulina cf. *pseudohirsuta* Nuttall
Bifarina vicksburgensis (Cushman)
Loxostoma amygdalaeformis (H. B. Brady) var. *delicata* Cushman
Anomalina cocoaensis Cushman
Cibicides cf. *perlucida* Nuttall

As a means of separating this horizon from the Red Bluff Oligocene, the writer lists the following species which appear to stop at the top of these clays.

Foraminifera

Gaudryina gardnerae Cushman
Pseudoclavulina n. sp.
Karreriella n. sp. (long)
Dentalina jacksonensis (Cushman and Applin)
Marginulina jacksonensis (Cushman and Applin)
Planularia danvillensis Howe and Wallace
Robulus arcuato-striatus (Hantken) var. *carolinianus* Cushman
Sigmomorphina jacksonensis (Cushman)
Nonionella jacksonensis (Cushman)
Angulogerina ocalana Cushman
Bolivina gracilis Cushman and Applin
Bolivina jacksonensis Cushman and Applin
Buliminella basistriata Cushman and Jarvis var. *nuda* Howe and Wallace
Reusella eocena (Cushman)
Uvigerina gardnerae Cushman
Uvigerina gardnerae Cushman var. *texana* Cushman and Applin
Uvigerina jacksonensis Cushman
Uvigerina topilensis Cushman
Eponides jacksonensis (Cushman and Applin)
Gyroidina danvillensis Howe and Wallace
Siphonina danvillensis Howe and Wallace
Globigerina ouachitaensis Howe and Wallace
Globorotalia cocoaensis Cushman
Anomalina costiana Wienzierl and Applin
Anomalina cocoaensis Cushman
Anomalina jacksonensis Cushman and Applin (thin sutures)

Of the ostracode species given in the check list, the only ones which appear to continue into the overlying Red Bluff are:[10]

Ostracoda

Bythocypris (?) *gibsonensis* Howe and Chambers
Cytheridea caldwellensis Howe and Chambers
?Cythereis montgomeryensis Howe and Chambers
Cythereis yazooensis Howe and Chambers
Cythereis florienensis Howe and Chambers

In the foregoing discussion the writer has enumerated the species of *Foraminifera* and *Ostracoda* which are useful for zonation of the Jackson Eocene. The check list (Table I) gives the full micro-faunal content of each of the samples studied. From it, the reader will be able to ascertain the many species present which have too long a range to be useful for accurate correlation purposes.

[10] Information obtained from H. V. Howe and J. W. Lea, who are describing the ostracode fauna of the Red Bluff group.

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GEOLOGICAL EXPLORATION BETWEEN UPPER JURUÁ RIVER, BRAZIL, AND MIDDLE UCAYALI RIVER, PERÚ[1]

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Rio de Janeiro, Brazil

ABSTRACT

The northern Territory of Acre, in the Alto Juruá River area, Brazil, and the middle valley of the Ucayali River, Perú, have not been studied geologically heretofore. It is a sparsely inhabited region. Flat plains, swamps, and tropical jungle make precise geological work in a short time rather precarious. However, as this contribution emphasizes, stratigraphical and structural conditions in the northwestern Territory of Acre, particularly the Serra do Môa region, show possibilities of important petroleum accumulations and the area deserves detailed surveying.

The sediments range in age from Lower Cretaceous to Pleistocene and are of continental and marine intermittent deposition, although poorly fossiliferous. No rocks of igneous origin were observed. Tertiary and Cretaceous formations of the Pachitéa, Pongo de Manseriche, and Contamana areas, Perú, can be stratigraphically correlated with those of the Serra do Môa and upper Juruá areas in the northwestern Territory of Acre.

The structural characteristics correspond with the physiographical features. The Serra do Môa Range, of Andean folding and apparently the last eastern spur of the Cordillera Oriental, is an anticline in partly Cretaceous beds, traversed by several tributaries of the upper Juruá.

Although oil seeps were not observed in the Serra do Môa region, they have been found in the headwaters of the Ahuaya River, a tributary of the upper Cashiboya River. The seeps occurred in faults in hard, red clay sandstones of the red-bed formation; the exact horizon from which the petroleum generated is not known since many seeps occur in Tertiary or Cretaceous outcrops. In the Pachitéa River district, seeps have been observed and drilling is planned for the near future by a private concern. The region of the upper Juruá geologically is a part of the potentially oil-bearing structural belt extending along the eastern foothills of the Andes, south through Bolivia into Argentina and north through eastern Perú into Colombia and Venezuela.

INTRODUCTION

This paper covers the writer's exploratory trip to the northern Territory of Acre, the Alto Juruá River, in Brazil, and through the lower and middle valley of the Ucayali River in Perú. The study of this part of the Territory of Acre was made for the Mineral Production Survey of Brazil, with the main purpose of investigating the petroleum possibilities and geologic structures in the region. The actual exploration work covered the period from September, 1935, to February, 1936, the writer doing most of it with no assistants, except native porters. The territory was covered in native canoes or

[1] Published with the permission of the director of the Mineral Production Survey of Brazil. Manuscript received, November 2, 1936.

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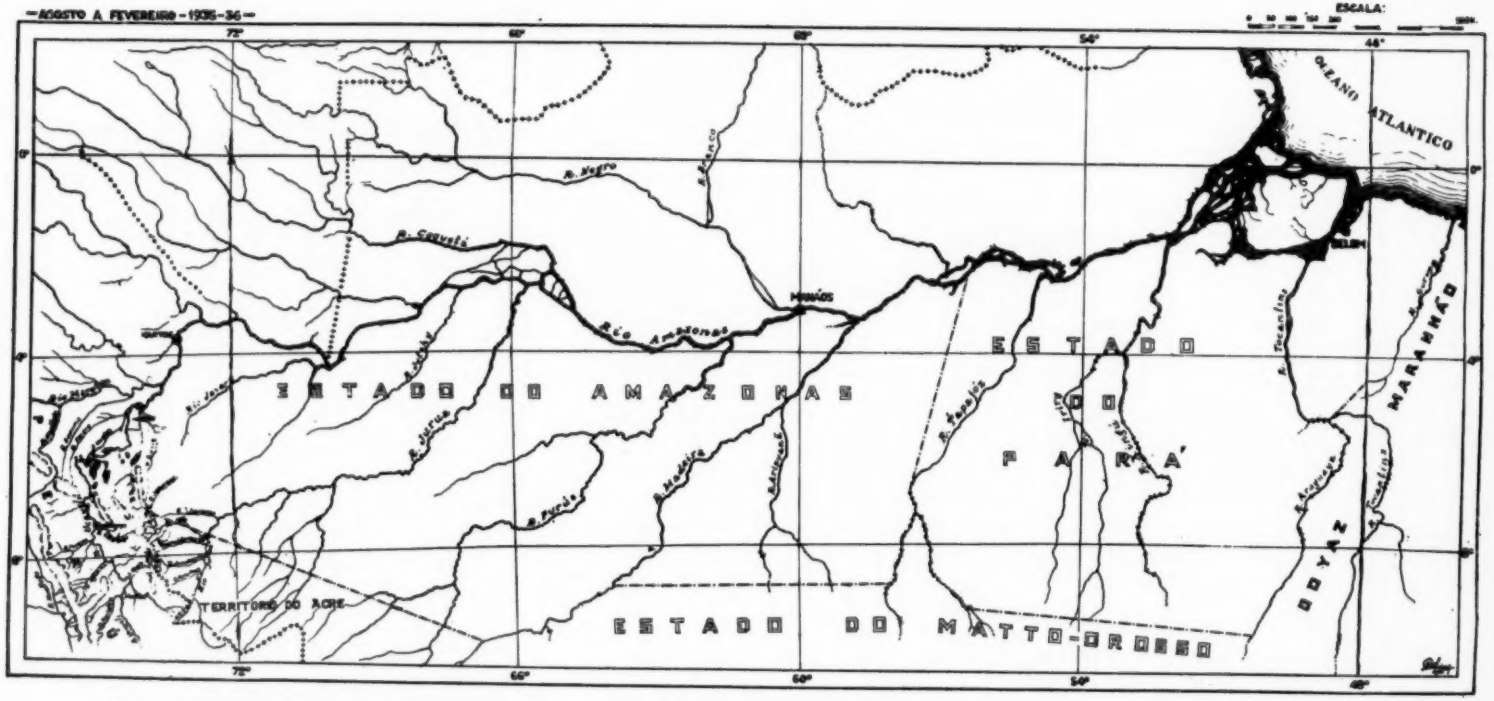

FIG. 1.—Area of valley of Amazon River showing region of Juruá and Ucayali rivers explored by writer. Figure 2 shows more detail in southwestern area.

on foot, the only means of transportation possible in that region. The place where the exploration started, Cruzeiro do Sul, is easily reached by steamers of the Amazon River Company. From Iquitos, Perú, several airplane trips were made along the Ucayali River in December, 1935.

The following are the main rivers explored by the writer along their entire courses or partly by land between their valleys: the tributaries of the Alto Juruá River in Brazil—Juruá-Mirim, Paraná dos Mouras, Môa, and Azul rivers; and the tributaries of the eastern margin of the lower and middle Ucayali River in Perú—Tapiche, Cashiboya, and Abujao rivers. The longest of the rivers, in Brazilian territory, the Môa River, extends approximately 180 kilometers in a straight line and, in Peruvian territory, the Tapiche River is nearly 300 kilometers long.

The entire area explored in Brazil and Perú extends approximately from Latitude 4°50′ to 8°30′ S. and from Longitude 72°50′ to 75° W.

Geological studies have never been made in this part of the Territory of Acre and there is no geological record known to the writer published on the area traversed by him in most of the valley of Ucayali in Perú, although oil seepages have been described in the Cashiboya River, which has been visited by several geologists in previous years.

The only bibliographical material on the areas adjacent to those explored by the writer in Perú, is limited to the reports by Singewald, A. Cabrera La Rosa, and Moran and Fyfe on the Pongo de Manseriche, on the Mareñon River farther northwest and the Pichis and Pachitéa Rivers farther southwest.

The flat plains, swamps, and tropical jungle, that cover most of the explored area, render any precise geological work in a short time rather precarious, particularly considering the difficulties with regard to tracing and finding good outcrops, which mainly occur in the river beds and streams, during the dry months.

Because of the very scarce paleontological material collected, all correlations drawn here tentatively may be subject to alterations according to the positive fossil evidence that may be found in the area in the future.

This paper, referring to an area studied for the first time, has, besides the purpose of a geological contribution on a hitherto unexplored region, the aim of emphasizing the possibly favorable conditions of petroleum occurrence in anticlinal structures of the Serra do Môa, in the Territory of Acre, Brazil.

The writer wishes to express here his gratitude to Djalma

Guimarães, director of the Mineral Production Survey of Brazil at the time of the writer's expedition and through whose active help its realization was possible.

PHYSIOGRAPHY

The area covered by the writer can be roughly limited by Cruzeiro do Sul on the upper Jurúa River, in Brazil, on the east; Contamana

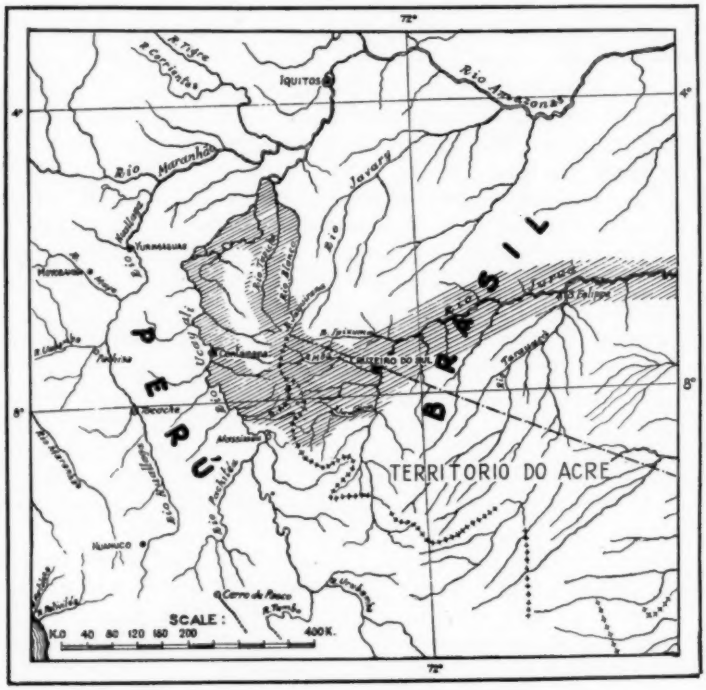

FIG. 2.—Area in Brazil and Perú covered by reconnaissance work of writer.

on the middle Ucayali River, in Perú, on the west; Requena, on the north; and Abujao River on the south. Most of it is a typical Amazon plain of vast low ground and extensive swamps, all covered by an exuberant jungle vegetation. With the exception of the settlements and villages on the upper Juruá and Ucayali rivers, the region is very sparsely inhabited, the inhabitants being natives and hunters or collectors of rubber in Brazil.

The part of the Territory of Acre, dealt with in this paper, is drained by the upper Juruá River system. This river is one of the longest tributaries of the Amazon River, measuring 3,283 kilometers from its headwaters in Perú to its junction with the Amazon. The northwestern course of the Juruá River is for the most part very winding, though accessible for steam navigation almost as far as the Peruvian border, where it is interrupted by the Cachoeira do Gastão rapids.

Near its mouth the Juruá River has an elevation of 43 meters; at the confluence with the Tarauacá River, its main tributary, the elevation is 108 meters; and at its headwaters 453 meters, thus giving a rather slight gradient for the great length of the river.

The middle and lower courses of the Juruá are so low that no outcrops of rocks are visible. The valley shows mostly recent clays and sands exposed on the "terras firmes"—higher ground not submerged during the periodical floods of the rainy season; the floods sometimes raise the level of the water to more than 10 meters above normal, thus inundating most of the low land of the valley.

The elevation of Cruzeiro do Sul is 180 meters and most of the area extending westward, toward the Peruvian border, along the valleys of the Môa and Juruá-Mirim rivers, is low and swampy with here and there "terras firmes."

About 100 kilometers directly west of Cruzeiro do Sul appears the first elevated hilly range, known as Serra do Môa. Where the Môa River traverses it, the range is approximately 400 meters in elevation. The Serra do Môa extends from here north-northwestward for about 50 kilometers, reaching the headwaters of the Jaquirana-Javary River on the Peruvian border. It appears in the valley of the Azul River, about 20 kilometers farther south, as Serra do Sunga. The continuation of the same range, though of considerably lesser elevation, can be traced in the uplifts observed south of the valley of Paraná dos Mouras and possibly in the valley of Rio Branco, a tributary to Juruá-Mirim River. It apparently continues north of Jaquirana River, as the range between the Tapiche and Blanco rivers in Perú.

The maximum elevation of the Serra do Môa is approximately 600–700 meters; the Serra do Sunga attains an altitude of about 350 meters, the average elevation of the surrounding region being approximately 200 meters.

The Serra do Môa Range does not form the water divide between the Juruá and Ucayali systems. The headwaters of the Môa and Azul rivers cross the range and take their waters about 15 kilometers farther west from level ground on the frontier. During the rainy sea-

son the area of the headwaters is an extensive swamp, with the headwaters of the Ucayali and Juruá rivers flowing respectively west and east. Thus the mountain range shown on maps as forming the border line, in reality does not exist, except for the area of the headwaters of Jaquirana River, at the northern extremity of the Serra do Môa.

Northward, the Tapiche River, in Perú, except for a hilly range that it crosses in its upper course at the place known as Five Rapids (Cinco Cachuelas) and the high area west of its upper valley, flows for most of its course through a low plain, the northern end of which is approximately 120 meters in elevation, at Requena, near the junction of the Tapiche with the Ucayali River.

Nearly 100 kilometers farther west from the Serra do Môa, on the banks of the Ucayali River, is a higher range, the Serra de Contamana, undoubtedly related to the Serra do Môa uplift. The Contamana Range, a spur of the Cordillera Oriental of Perú, crosses the Ucayali River at the place called Canchahuaya, and extends southeastward for approximately 80 kilometers, where it possibly dips under the plain in the valley of Cashiboya River. The Contamana Range is 600–900 meters high; it has an eastward extension, known as Contaya, at the headwaters of the Contaya and Humaytá rivers, tributaries of the upper Tapiche River.

Southeast of the Contamana Range, a distance of nearly 100 kilometers in a straight line, is a group of uplifts, known as the Cerros de Utuquinia, between the upper Utuquinia and Abujao rivers. The highest points of this range, well observable from airplane, reach 1,000 meters.

South of the Abujao River another range is seen on the horizon, this apparently having not yet been explored. The surrounding area is rather low, with an average elevation of approximately 160 meters.

Most of the hilly ranges and uplifts, mentioned here, though very important from physiographical and geological viewpoints, are not shown on most of the known maps, and, with regard to Brazil, have not been described or mentioned before.

STRATIGRAPHY

The age of the sediments in the area explored can be classified as ranging from Lower Cretaceous to Pleistocene. They are apparently of both continental and marine intermittent deposition, although poorly fossiliferous, especially in the Territory of Acre. No rocks of igneous or tuffaceous origin were observed in the region.

A close analysis of many outcrops permits a tentative correlation with the extension of the same sediments in Pongo de Manseriche and

Pachitéa River in Peru. The latter sediments have been described on a paleontological basis by Singewald, Moran and Fyfe, and others.

The oldest rocks of the region appear in several outcrops in the Serra do Môa anticline, where the Môa River traverses it in a deep canyon, forming rapids known as Cachoeira do Môa. The Môa sandstones, as the writer called the outcrops of the rocks in the rapids of the Môa River, are light or cream-colored, hard and compact, appearing with a north strike and a dip 20°–30° west.

Here were also found hot-water springs issuing from fissures in a bed of somewhat coarser sandstones. Abundant chert boulders and many pyritic concretions are found in the vicinity of the springs.

FIG. 3.—Môa River rapids, upper Juruá River.

The Môa sandstone can be tentatively correlated with the Pongo sandstone, in Perú, as described by Singewald. Though fossils were not found in this formation in the Territory of Acre, or in the Peruvian outcrops, the position of the Pongo sandstones underlying fossiliferous Senonian beds gives them an age limit as Lower Cretaceous, possibly Neocomian.

Following the Môa sandstones near the headwaters of the Azul and Môa rivers are rather extensive outcrops of dark blue and gray clay-shales, very calcareous sandstones, and thin limestone intercalations. Some of the shales are brick-red in color and contain calcareous concretions. In many outcrops these beds show a pronounced west dip and are thus apparently concordant with the underlying Môa sandstones.

On the banks of the upper Paraná dos Mouras River light gray limestones form beds approximately 20–50 meters thick. The same limestone beds were found in many places in the upper Abujao River; apparently they occur in the upper and middle part of the formation. Though the rapid observations in the valley of Môa failed to disclose fossils, a very fossiliferous outcrop of dark blue shales was found on the upper Abujao River, somewhat below the Quebrada Repollo. The fossils, different species of lamellibranchs and gastropods, were unfortunately destroyed and lost during the voyage.

This formation is well exposed in the Abujao River, where the successive dark blue, gray and red clay shales and limestones show a constant dip of 5°–20° W., with an average total thickness of over 300 meters. The formation is apparently of shallow-water origin with intermittent periods of vàrying conditions of deposition, as can be deduced from the sequence of dark blue to light shales, sandstones, and limestones, with a predominating calcareous content throughout the formation.

In the same sedimentary group one may possibly include the hard gray, very fine-grained sandstones that appear in the rapids at the headwaters of the Môa, Azul, and Juruá-Mirim rivers, forming an edge of an apparently uplifted block limited by an extensive north-south fault.

The previously mentioned beds are overlaid with fine to coarse quartzose sandstones, which the writer called Sungarú sandstone, as they were first observed on the upper Azul River, showing good exposures near the mouth of a small stream called the Igarapé Sungarú.

The Sungarú sandstone is characterized by a coarse, white, conglomeratic basal bed, with many pebbles more than 1 centimeter in diameter, though most of it consists of a finer, light-colored, and cross-bedded sandstone that forms the hilly elevations of Serra do Sunga. At the Serra do Sunga, the sandstone beds have a northeast strike with slight east and abrupt west dips. Their thickness in some outcrops exceeds 150 meters.

Fragments of fossilized wood were found in similar sandstones in some creeks in the Môa River valley. It is thus possible that the fossil woods, not yet identified, belong to the Sungarú sandstones, though they may have been transported from some overlying Tertiary beds. Other fossils that could be related to the sandstone beds were not observed in the area.

Although lacking fossil evidence, the Sungarú sandstones appear in lithologic character very similar to the Huancanqui sandstones of the Pongo de Manseriche, as described by Singewald, or the Sugar sandstones of Moran and Fyfe in the Pachitéa area.

Covering the Sungarú sandstones, there extends a formation very widely distributed in the upper valley of Juruá River. It is characteristically exposed near the town of Cruzeiro do Sul; therefore, the writer called this formation—composed predominantly of red clays with limestone layers, shales, and sandstones—Cruzeiro red beds.

The Cruzeiro red beds were first observed in the middle reaches of the Juruá River, somewhat above the town of São Felippe. In all the outcrops these beds are composed of light-to-dark red and in places purplish or violet clays and sandstones, nearly everywhere with light greenish intercalations of bands of limestones or calcareous clays ranging from a few centimeters to several meters thick. The lime-

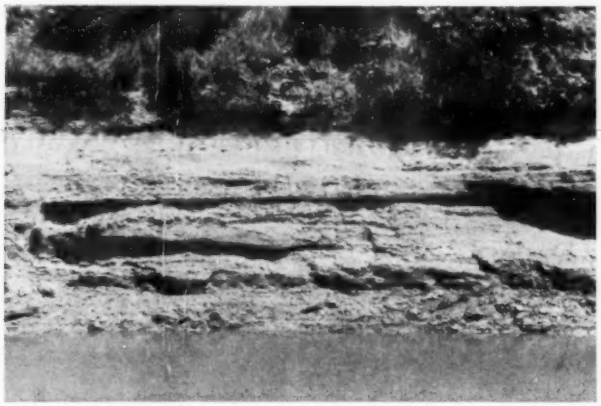

Fig. 4.—Cruzeiro red beds, upper Juruá River.

stones are in many outcrops cavernous. The formation appears through most of the valley of the upper Juruá River and its tributaries in the Territory of Acre. The beds, though distinctly cross-bedded, have here a generally east regional dip of a few degrees.

Crossing the Peruvian border the formation continues in the upper valley of Tapiche River. Here, besides limestone intercalations, layers of white or rosy gypsum are also found.

In that part of the upper Tapiche River, known as the Five Rapids, the river traverses a range of hills, approximately 300 meters high, with outcrops of very hard and compact dark red claystones with white bands. They are not stratified and can be included in the red-beds formation.

Below the Contaya River, a tributary to the Tapiche River, is an outcrop of red shales and sandstones with dark gray clay-shale in-

tercalations, in which unrecognizable carbonaceous fossils were seen.

The red beds were again observed on a "tierra firme" near Requena, on the Ucayali River. They also appear in the middle and upper course of the Abujao River, an affluent of Ucayali River, between Pucalpa and Massissea in Perú. Here were found several fossiliferous outcrops though the fossils collected were unfortunately lost during the trip.

Near the upper course of the Cashiboya River, a tributary to the Ucayali River, in the region of the Serra de Contamana, similar red, hard claystones with white bands, were observed. Here, along a hilly

FIG. 5.—Red beds on Abujao River, Perú.

range, which is the southern continuation of the Serra do Contamana, they form extensive outcrops in the upper Ahuaya River, a tributary of the Cashiboya River, where several oil seeps appeared from fissures and faults in the rocks. These have been known in the upper Ahuaya River, and at Quebrada Olhante, for a number of years. It is quite evident that the oil has migrated along the observable faults from some lower horizon. Whether this horizon belongs to the same formation as the red beds or to some lower one is an open question.

No fossils were found by the writer in the red beds described. The upper age limit of the Cruzeiro red beds is shown by a fossiliferous outcrop, discovered by the writer at Aquidabam on the middle Juruá River, about 50 kilometers below the town of São Felippe and near the mouth of the Tarauacá River. Some of the fossils were classified by Mathias Roxo, of the Geological Survey of Rio de Janeiro. These

were fragments of a jaw bone of a crocodile, provisionally determined as *Brachignathosuchus brasiliensis*, belonging to a species identical with that described by Ch. C. Mook in 1921 and found in the upper Purús River, though if the fragments found by the writer should belong to a new species, such species would be called *Br. juruensis*.

To the same collection also belong several fossil vertebrae of crocodiles and a rib of a mammal not yet classified. Lamellibranchs, some of *Unio* sp. and *Castelia* sp., gastropods of the genus *Conus* and *Masalia*, vegetable remains, and leaves of a *Dicotyledonean* were also found in the same deposit, interbedded in gray-greenish, well stratified clays with abundant cherty concretions.

These fossils, though as yet not definitely classified and studied, nevertheless permit one to place the Aquidabam beds in the late Tertiary, most probably Pliocene age; thus the beds are evidently of terrestrial fresh or brackish-water origin.

Consequently the underlying Cruzeiro red beds are of late Cretaceous–Middle Tertiary, Neogene age. They form part of the vast Cretaceous-Tertiary belt that extends along the foothills of the eastern Andes ranges for nearly the whole length of the South American continent.

The Cruzeiro red beds are in part contemporary with the Capas Rojas of Cabrera La Rosa or the red beds of Singewald, equivalent to the Formacion de Puca of Steinmann, or the Tararenda formation of Heald and Mather in southern Bolivia, or again the Formacion Petrolifera of Brackenbush. According to Bonarelli, the last named is composed of the "Tertiario Subandino" and the Upper Cretaceous "Areniscas Superiores" beds. This formation is apparently of an intermittent land and water origin. All its outcrops are very poor in fossils, which makes a more accurate subdivision at present hardly possible. The persistent red coloration of the beds and an eolian facies suggest rather arid climatic conditions at the time of deposition of the upper horizons of this formation as observed in many outcrops in the stated areas.

The Quaternary sediments in that region are represented mostly by outcrops of unstratified clays of white, yellow, or darker colors. They form extensive beds, in places as thick as 15 meters, covering great areas of the region. Some of the outcrops show remains of a still modern vegetation and thin layers of carbonaceous material. A rich fossil fauna of mammals is known in the Pleistocene beds of the valley of Huallaga River, in Perú. Fragments of bones and maxillaries of mastodons were also found in the valley of the upper Juruá River (near the Peruvian border) at the rapids known as Cachoeira do

Gastão. Though evidently of Pleistocene age these fossils of Gastão were probably brought by the river stream from the headwaters to the place of their present occurrence.

Fragments of fossil bones of the genus *Toxodon* are quoted by Roxo as presumably found in the Juruá Valley.

The recent and actual sediments are composed of a great variety of loose sands, clays, vegetable debris, and river gravels. They form many of the "terras firmes" along the river banks, but to a great extent they are carried downstream by the yearly Amazon floods.

TECTONICS

The structural characteristics of the region correspond with its physiographical features. The Cruzeiro red beds are, in most of the valley of the Juruá River, flat and cross-bedded, and only in the proximity of the Serra do Môa do they show local east dips of approximately 10°–15°.

The Serra do Môa is an anticlinal fold with its axis striking approximately north-northwest. In the area of upper Môa River, the eastern flank of the structure has a rather slight dip, but the western is considerably steeper, averaging 30°–40° W.

The structure, extending across the valley of the Môa River, continues to the headwaters of the Jaquirana and Ipixuma rivers farther north, and reappears as the Serra do Sunga in the valley of the Azul River, as well as in slight uplifts in the region of Paraná dos Mouras farther south.

The Serra de Contamana in the valley of the Ucayali River farther west in Perú was very rapidly observed by the writer, but it seems to represent a partly monoclinal type of structure with north-south faults. This range is directly related to the Cordillera Oriental uplift, being contemporary with that of the Serra do Môa. As it is located farther east from the main orogenic center, in the Andes, its folding is more gentle and less fractured than that of the Serra de Contamana. This folding is apparently in part older than the formation of the Cruzeiro red beds, thus being of later Cretaceous or early Tertiary age. The tectonic activity, nevertheless, continued through the Tertiary as isostatic movements, as shown by the slow general uplift of the area between the actual "thalweg" of the Juruá and Ucayali rivers. This regional uplift explains the canyon of the Môa River, which this river cuts across the range of Serra do Môa.

The waterfalls in many of the headwaters of the rivers, as Cachoeira do Môa, Cachoeira do Monaiz, and Cachoeira do Juruá-Mirim, are apparently due to faults of a slight eastern downthrow.

The actual tectonic activity of the region is reflected in the slight seismic movements, as known to occur in the Serra do Môa and Serra de Contamana areas.

PETROLEUM INDICATIONS

Though oil seeps were not observed by the writer in the Serra do Môa region, they were found in the headwaters of the Ahuaya River, tributary to the upper Cashiboya River, approximately 30–40 kilometers west of the Brazilian-Peruvian border. The seeps occur in faults in hard, red clay-sandstones of the red-bed formation. It must be said that the exact horizon in which the petroleum originated in the Peruvian "montaña" is not known, since the many oil seeps occur either in the Tertiary or Cretaceous outcrops. The following are the seeps known in the Contamana district, as given by the Ministerio de Fomento of Perú, in April, 1935. The distances are measured from the town of Contamana on the Ucayali River: Agua Blanca, 60 kilometers; Quebrada Olhante, 18 kilometers south; Quebrada Vivian, 18 kilometers south; Quebrada Shaypaya, 50 kilometers south; Quebrada Amiapa, 50 kilometers south; Quebrada Amapa, 50 kilometers south. In all, according to Cabrera La Rosa, 15 seepages are known in that area; some of these were observed by the writer.

In the Pachitéa River district there are also several oil seeps as stated by Moran and Fyfe in 1933, and by Cabrera La Rosa. Here, it is reported that drilling is planned for the near future, by a private concern.[3]

As the Cretaceous-Tertiary oil-bearing belt extends across the frontier into Brazil where are favorable, closed structures such as the Serra do Môa anticline and its extension, there are logical possibilities of petroleum accumulation in the deeper strata of the structures. The absence of active oil seeps in the Serra do Môa area is mainly due to its being less affected by faults than the neighboring Serra de Contamana, in Perú, with its many seeps. Detailed surveys and eventual drilling of the promising northern Territory of Acre region in Brazil are thus quite justified and should be recommended.

GENERAL CONCLUSIONS

The total scope of the writer's observations, together with the geological data known on the areas in Perú, contiguous to the Territory of Acre, allows emphasis to be placed on the following conclusions.

[3] Oliver B. Hopkins, "Petroleum Development in Peru during 1935," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 118 (Petroleum Division, 1936), p. 485.

1. The Tertiary and Cretaceous formations of the Pachitéa, Pongo de Manseriche, and Contamana areas in Perú extend eastward and can be stratigraphically correlated with the Serra do Môa and upper Juruá areas in the northwestern Territory of Acre.

2. The Serra do Môa Range is of Andean folding and is apparently the last eastern spur of the Cordillera Oriental. It is an anticlinal fold in partly Cretaceous beds, extending not along the water divide of the Juruá and Ucayali rivers, but mostly east of it, thus being traversed by several tributaries of the upper Juruá.

3. The upper Juruá area geologically is a part of the potentially oil-bearing structural belt that includes the Huallaga, Marañon, and Ucayali basins and extends along the eastern foothills of the Andes, south through Bolivia into Argentina and north through most of eastern Perú into Colombia and Venezuela.

4. The stratigraphical and structural conditions of the northwestern part of the Territory of Acre, and particularly the Serra do Môa region, deserve attention and detailed surveying, as they show possibilities of important petroleum accumulations.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 1 (JANUARY, 1937) PP. 111-112, 1 FIG.

GEOLOGICAL NOTES

SULPHUR BLUFF FIELD, HOPKINS COUNTY, TEXAS

The Sulphur Bluff field is located in Hopkins County, Texas, about 14 miles northeast of Sulphur Springs, the county seat. It is also about 16 miles S. 70°W. of Talco, Titus County, Texas.

The history of Sulphur Bluff is similar to that of Talco, in that both are fault structures along the Powell-Mexia fault line, both tested dry in the Woodbine, and for more than 10 years both have been known as almost certain closures. Therefore, after production was obtained at Talco from the Paluxy formation, Sulphur Bluff appeared to be a first-class prospect.

The discovery well, Hager, Russ, and Luse, J. E. Worsham No. 1, was completed on July 15, 1936, as a 530-barrel pumper from a total depth of 4,500 feet in oil sand. With a surface elevation of 440 feet, this well encountered the top of the Paluxy at 4,450 feet, and the top of the oil sand at 4,480 feet. The second well, Hager, Russ, and Luse, Worsham No. 2, located 890 feet south and 572 feet west of the discovery well, was completed on August 23, 1936, flowing 545 barrels per day through open 2½-inch tubing. With a surface elevation of 429 feet, this well encountered the top of the Paluxy at 4,487 feet, the top of the oil sand at 4,527, and drilled oil sand to a total depth of 4,577 feet. In this latter well, the water level was established between 4,563 and 4,577 feet. To date, four additional flowing wells have been completed. All six wells encountered a good sand section, averaging 40 feet of oil sand to 100 feet of Paluxy section cut.

The oil produced at Sulphur Bluff corresponds with that produced from the Paluxy at Talco, being a mixed base crude, predominantly asphaltic, black in color, and with a gravity of about 22°.

The structure at Sulphur Bluff is a closure along a fault with downthrow toward the north, having about 375 feet of displacement in the Pecan Gap chalk. Surface geology, core drilling, and reflection shooting indicate that the Sulphur Bluff fault is parallel and *en échelon* with the Talco fault, the northeast end of the Sulphur Bluff fault being about 1½ miles north of the southwest end of the Talco fault. The dip of the Paluxy on the upthrown side is about 250 feet per mile toward the south. The field will probably have a maximum width of about 3,000 feet and is now proved for a distance of one mile parallel with the strike.

Immediate development at Sulphur Bluff includes sixteen wells to be drilled by Hager, Russ, and Luse, and a pipe line to be built by Golding and Murchison to take the oil from these wells.

E. G. THOMPSON

TYLER, TEXAS
November 15, 1936

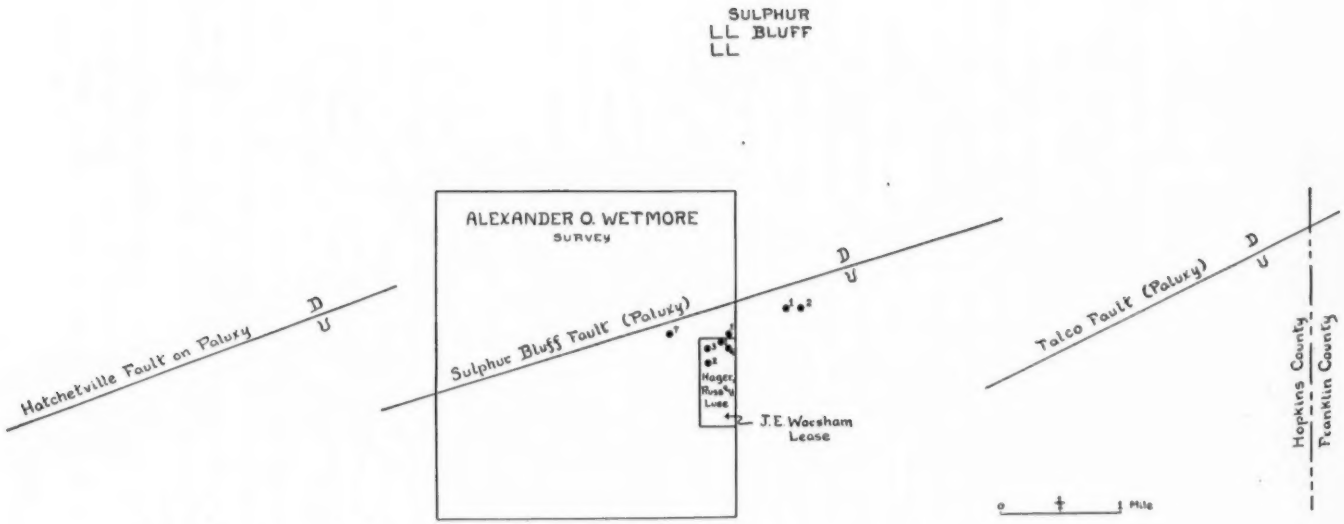

FIG. 1.—Sketch map showing location of faults in Paluxy formation and oil wells in Sulphur Bluff field, Hopkins County, Texas.

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VOL. 21, NO. 1 (JANUARY, 1937), PP. 113-119

DISCUSSION

WILLIS, ON RIFT VALLEYS OF EAST AFRICA[1]

A facetious critic once remarked, "Willis writes so well he makes me believe things that are not true." The writer, having previously adopted several of the ideas so well presented by Willis, knows that agreement on such points arises from something deeper than his charming and lucid style. His book on African rifts is a monographic study, has large pages with big type, and is beautifully illustrated.

The arrangement of subjects and the choice of material under each subject are those of the author's line of thought, which is theoretical rather than descriptive. Arguments for his opinions appear under all headings. This arrangement is excellent for the speculative purpose, but, in spite of a good index, it is less well adapted to the systematic organization of data, and those seeking specific information for their own studies will find it more readily in the books of Krenkel[2] and Gregory.[3]

The main headings are: Historical Retrospect (development of theories of normal faulting); Continental Features (of Africa) and Their Meaning; Genetic Hypotheses; followed by a series of regional descriptions and explanations of structure—Coastal Region, Plateaus, Lake Albert Rift, Mount Ruwenzori, Lake Edward-Kivu Downwarp, Tanganyika Trough, Rukwa Trough, Nyasa-Luangwa System, Ruaha Trough, Gregory Rift Valley (a new term for the northern part of the Eastern Rift), Lake Rudolph Basin; after which are discussions—Vulcanism and Structure, Earthquake Conditions, and Gravity Tests.

Among American and a few foreign geologists the idea appears to be growing that many normal faults, such as the rifts of East Africa, are upthrusts, probably connected with deep compressive forces, and that one rarely finds pure gravity faults due to block subsidence under lateral tension. The opposite view, however, still persists, especially in Europe, where it has been maintained by Gregory,[4] Evans,[5] and to some extent van Werveke[6] and Wilser.[7] Willis' new evidence of the upthrust nature of the East African rifts is most welcome.

[1] Bailey Willis, "East African Plateaus and Rift Valleys," *Carnegie Inst. Washington Pub. 470.* 358 pp., 72 pls. (including 22 maps), 16 figs., 1 colored frontispiece. 9×11.5 inches. Washington, D. C. (1936).

[2] Erich Krenkel, *Die Bruchzonen Ostafrikas; Tektonik, Vulkanismus, Erdbeben und Schweranomalien.* 184 pp., 14 figs., 2 pls. Gebrüder Borntraeger, Berlin (1922).
———, *Geologie Afrikas.* Vol. I, 461 pp., 22 pls., 105 figs. Gebrüder Borntraeger, Berlin (1925).

[3] John Walter Gregory, *The Rift Valleys and Geology of East Africa.* 479 pp., 44 diagrams, 5 maps. Seeley, Service and Company, Ltd., London (1921).

[4] J. W. Gregory, *op. cit.*

[5] John William Evans, "Regions of Tension." Presidential address, *Quar. Jour. Geol. Soc. London,* Vol. 81 (1925), pp. lxxx–cxii.

[6] Leopold van Werveke, "Der Verlauf und das Alter der Hauptwerfungen und der übrigen wichtigeren Störungen und Bewegungen im Gebiet des Mittelrheintalgrabens," *Heidelberg. Akad. Wiss., Math.-Nat. Klasse,* Ab. 21 (1934). 114 pp. (A posthumous publication.)

[7] Julius Ludwig Wilser, "Die Entwicklungsstadien des südlichen Rheintalgrabens," *Neues. Jahrb. f. Min.,* etc., Beilage-Bd. 62 (1929), Abt. B, pp. 1–44; 1 sketch map.

The author gives rather convincing physiographic evidence that most, if not all, the displacement on the rifts occurred in the Pleistocene. Previously East Africa had been a low peneplain for which Willis assumes an average seaward slope, and thereby is able to estimate roughly the former elevation of places at various distances from the coast. As a result it appears that the floors of several rift valleys now stand higher than they were before the faulting, if it is assumed that the faulting is not later than the uplift of the plateaus. This seems a safe assumption, for, in the mind of the writer, the uplift is closely related to tilting which, in turn, is systematically tied to the faulting. Uplift and faulting, or its virtual equivalent, monoclinal flexing, probably were synchronous. Willis estimates that the floor of the Rukwa graben now stands about 1,940 feet higher than the original peneplain at that place, the floor of the Luangwa graben more than 2,500 feet higher, that of the Ruaha graben about 400 feet higher, and that of the Gregory Rift Valley about 3,000 feet higher than its pre-fault elevation.

The floors of other grabens are lower than before the faulting, some lying below sea-level, yet, according to Willis, these did not "fall," but must have been *pushed down* between inclined thrust planes by lateral compression, which evidently still holds them down, because in the rift valleys the gravity anomalies are strongly negative. In other words, if lateral tension permitted gravity to move the great "sunken" blocks between the main faults, their floors would rise, not sink. Some of these valleys are more than 50 miles across and hundreds of miles long, indicating the magnitude of blocks that lateral compression apparently can hold down against an isostatic tendency to rise.

Willis states further that the plateaus, as a whole, have strong positive anomalies. Presumably they are maintained at their present height by the same lateral compression that holds the rift blocks down. (This dual effect of the thrusts is permitted by their slope.) If so, the width of the plateaus, measured in hundreds of miles, raises a problem in the strength of rocks. Presumably Willis feared no interference with the idea of lateral compression when he postulated an old fashioned gravity fault along the eastern coast of Africa, for this may be only the base of a shallow block that slid into the Indian Ocean. Nor does he say that complete isostatic adjustment, lifting the floors of the grabens and lowering the plateaus, would entirely wipe out the local structural relief of the grabens, but his diagrams of gravity anomalies indicate a tendency in that direction.

The early gravity determinations by E. Kohlschütter are analyzed by Willis more thoroughly than by Krenkel. Willis had access also to the recent unpublished determinations by E. C. Bullard of Cambridge University. He quotes Bullard as saying:

> The Rift floor can not have "fallen in," for if released it would rise, not fall. The gravity results therefore give what seems a conclusive decision between the "tension" theory of Gregory and the "compression" theory of Wayland. The tension theory appears to be untenable. (P. 343.)

Credit for originating an essential part of the preceding theory probably belongs to Vening-Meinesz[8] who applied it to the long strip of negative anom-

[8] F. A. Vening-Meinesz, "Gravity Anomalies in the East Indian Archipelago," *Geogr. Jour.*, Vol. 77 (April, 1931), pp. 323–37, map. See also his "Ergebnisse der Schwerkraftbeobachtungen auf dem Meere in den Jahren 1923–1932," *Ergebnisse der Kosmischen Physik*, Bd. 2 (1933). Separate of 60 pp., 4 maps, 7 figs.

alies which follows the seismically energetic ocean deep near Sumatra and Java, concluding that the floor of the trough is being pushed down by the lateral pressure of mountain-making forces now acting across it.

Readers of the last chapter, on "Gravity Tests," should be aware that in Figures 8–16 entitled "Free-air anomalies," the dashed lines do not directly portray anomalies, but represent what the ground elevation would be if it were in isostatic equilibrium.

In slight disagreement with earlier observers, Willis thinks that downwarping rather than faulting determines the eastern sides of the valleys of Lake Albert, Lake Edward, and in part of Lake Tanganyika. If the west-facing slopes are due to faulting, the scarps have been greatly subdued, but, unfortunately, Willis does not discuss this possibility. Johnson[9] and Gilbert[10] recognized its significance in a similar case, the graben of Klamath Lakes, southern Oregon. Field work and physiographic analysis by Johnson, presented more fully by Gilbert, showed that the fault along the west side of Klamath Valley, near the lakes, is much older than that along the east side. Since the western wall of the graben was completed before the eastern wall began to break, it is obvious that the Klamath graben is not a block that subsided as a mechanical unit. For such cases the term "block" has no more than descriptive value, designating merely the rock segment that happens to lie between two independent faults. Possibly in most cases this is all that the term should connote, for unless there be marked difference in the appearance of opposing scarps, or evidence obtained at the intersection of the two sets of corresponding joints that are parallel with the opposing faults of the scarps, we have no way of telling whether movment on the two walls of a graben occurred at the same or at different times.

Previous descriptions of the Western Rift zone of East Africa have led the writer to suspect that its relatively low eastern walls, north of the Kivu scarp, not only are less precipitous than the western walls, but also are more thoroughly dissected. In the southern part of the Western Rift zone, near Lake Kivu, and along the Eastern Rift zone ("Gregory Rift Valley" of Willis), the literature suggests reversal of this order, the faults which face a graben from the west having what seems like the older topography, judging from descriptions. This apparent relation is suggested with reservations, for the writer has not been in East Africa, and the publications examined do not directly consider the relative ages of opposing faults. The more gentle slope on one side of a rift valley may be the result of flexing, as Willis suggests, or of faulting at lower angle, but this would not wholly explain the general appearance of older topography (if such it be) along the more subdued side of the valley. In a region of normal faults one commonly finds that the older faulting was accompanied by greater flexing of the rocks, which may increase the difficulty of detecting the greater age of one set of faults, but this is just the type of problem that a skilled physiographer, such as Willis, might well have tackled.

Consideration of the relative ages of the faults opens a new world of thought. Previous descriptions suggest to the writer that in the Eastern or "Gregory" Rift zone, the sharper scarps generally are those that face west,

[9] Douglas W. Johnson, "Block Faulting in the Klamath Lakes Region," *Jour. Geol.*, Vol. 26 (1918), pp. 229–36.

[10] Grove Karl Gilbert, "Studies in Basin Range Structure," *U. S. Geol. Survey Prof. Paper 153* (1928), pp. 76–85.

and in the Western Rift zone those that face east, that is, near both sides of the basin the fresher scarps tend to face its center, occupied by Lake Victoria. The marked exceptions lie mainly near the southern end of the faulted region. This order is the reverse of that suggested by the physiography of the Basin Ranges of the United States, in which the fresher and presumably younger scarps seem generally to face away from the center of the Great Basin. Relative "freshness" in such cases may be due to difference in fault-dip or in amount of associated flexing of the rocks, points which can not be settled until more is learned about its distribution in various parts of the basin. In further contrast to the rifts of East Africa, the scarps of the Great Basin have forms which suggest to the writer that the apparently older scarps generally are the larger and, if not too greatly eroded, may command the landscape, as do the Sierra Nevada and the Wasatch, faced by lower, but fresher looking, antithetic scarps. The general suggestion is that, after the second or antithetic set was initiated, only small renewals occurred on the first set, for these belated efforts seem not to have enabled the older scarps to regain youthful forms, much above their bases.

Willis increases the uncertainty in this matter by his interesting treatment (p. 171) of the relatively steep eastern declivity of the Sierra Nevada, which has a mean slope of 25–28°, and which he regards as a distributed fault or fault zone in which the slipping was divided among many parallel fractures. Along the slope he finds deeply weathered rock ("sapropelite"), indicating, in his opinion, that remnants of peneplain ground still cap some of the faulted strips of the mountain front. Therefore, he concludes, the mountain front can not be a receded fault scarp that originally had the usual steepness, because during recession the weak sapropelite would have been swept away. This argument seems good, assuming that the sapropelite represents the weathered material of the original peneplain, but it does not rule out the possibility that the eastern slope of the Sierras may be a monoclinal flexure accompanied by sympathetic faulting. Moreover, the early movements when the mountains were still rather low, may have ceased temporarily, long enough to permit deep weathering in wide valleys eroded on a growing flexure. The local effect of hot springs in decomposing granite may simulate weathering. The writer, for one, would appreciate knowing the precise localities on the Sierran front where one can find sapropelite.

The application (pp. 168–71) of the same explanation to Mount Ruwenzori seems less felicitous, for its contours (Plates 32 and 33) only weakly suggest a tilted fault block. (The contours of Plate 32 do not seem to agree with the profile across the mountain in Plate 35-B.)

In this connection comparison should be made with the analogous Wasatch scarp, which also has higher land behind it, the topography of which is much older than that of the scarp itself. Eardley[11] believes that the Wasatch fault broke along the western base of a belt of hills that rose 3,000 feet above what is now the top of the scarp, but he does not consider the possibility that much of this greater height may have resulted from monoclinal flexing before, or possibly during, the formation of the present scarp. A neglected point of much significance is that the location of the old belt of hills, parallel with the

[11] Armand Eardley, "Strong Relief before Block Faulting in the Vicinity of the Wasatch Mountains, Utah," *Jour. Geol.*, Vol. 41, No. 3 (April–May, 1933), pp. 243–67.

present scarp and athwart the trend of the formations, requires an older period of deformation, either early displacement along the Wasatch fault, making a scarp that nearly vanished before the present scarp was formed, or early monoclinal flexing of the area between the present scarp and the crest of the range.

Recognition of the difference in age of opposing faults opens the way for new concepts concerning the mechanics of their formation, which will be discussed elsewhere. Narrow high horsts within wide grabens, as in the valleys of the Rhine and of Lake Tanganyika, seem rather inconsistent with the tensional theory of normal faulting. Willis, believing that fault blocks move up and down as mechanical units, rather than by alternate tilting from successive movement along their walls, infers underthrusts along the margins of the two large horsts of Lake Tanganyika, named Mount Ubwari and Mount Kungwe. He discovered no field evidence of the supposed thrust faults, and reports that, near Mount Kungwe, Fourmarier and Teale found only steep normal faults.

Mount Ubwari is a high narrow block in the northern part of the Tanganyika trough, 15 miles from the main western wall. It is 33 miles long and about 4 miles wide, with straight, almost undented, parallel sides that for most of their length trend N. 10° E. On the topographic map (Plate 18, p. 91) the scarp facing east seems steeper than that facing west, but as mapped, the two scarps show little difference in degree of dissection. Although the difference in slope of the two sides of the horst is not nearly as great as that of the corresponding sides of the whole trough, the horst harmonizes with the graben in that its steeper wall faces east. Further resemblance between the sides of Mount Ubwari and those of the main graben is found in the fact that their east-facing scarps are much higher than those facing west. As measured from its base under the lake, the east-facing scarp of the horst is about 3,600 feet high, the west-facing scarp about 2,000 feet high.

These similarities suggest to the reviewer that the western scarp of Mount Ubwari may belong to a relatively older series of west-facing step faults, formed shortly before the east-facing set. According to this interpretation the largest member of the east-facing set created a trough at Tanganyika merely because it broke in front of the main fault of the older set. Had it broken behind the latter it would have created a horst. This may have happened at Mount Ubwari, the top of which would be tilted eastward by the earlier movement, when the west-facing scarps were active, but, inferentially the direction of tilting later was reversed westward by the greater displacement which then occurred along the eastern side of Mount Ubwari. The separate completion of the younger or eastern fault made the present horst. Since the older fault lies only 4 miles west of the younger one, its westward dip may have been increased by the tilting of the country which accompanied the formation of the younger fault.

In this theory of the writer, the mechanics involved is that of the creation of step faults along curved paths, in two sets of different age, that curve downward in opposite directions. In normal faulting, if the radius of fault-curvature equals the width of country tilted, the country is not elongated across the fault, and indeed, may be shortened, if the radius of curvature be less than the width of the tilting, or if there be sufficient flexing or other plastic adjustment. In each phase of movement the upthrows on all faults within

a unit area of deformation are all toward one side of the faults, i.e., during that phase they create only like-facing scarps. This process is more probable than that of the direct uplift and subsidence of indefinitely straight-sided blocks between walls inclined to the direction of movement, because, under lateral compression, the vertical movement of such blocks would consume more energy, if indeed, it be not impossible.

This flight of fancy by the writer calls for the temporary indulgence of the reader, especially of Willis, who himself soared high enough when, without evidence, he postulated thrust faults along the horsts in the Tanganyika graben, a region of normal faulting and not of folding, which is the characteristic accessory of thrust faulting.

Willis (Plate 3, p. 31) treats the Rukwa and Tanganyika faults, which trend about N. 30° W., as the result of a clockwise horizontal force-couple that trends N. 15° E. His hypothetical "underthrust" faults along the Kungwe horst also trend N. 30° W., which is normal to the direction (N. 60° E.) that they would have followed had they been produced by the force-couple. His supposed "underthrusts" along the Ubwari horst trend N. 10° E., being thus out of place by 50°. The writer takes a peculiar interest in the trend of the Ubwari faults, and of the parallel northern 80 miles of the west shore of the lake, for this trend (N. 10° E.) makes an angle of 5° with the hypothetical force-couple and of 40° with the main Tanganyika line of faulting. A southward projection of these three faults of the Ubwari line meets the east side of the Tanganyika line so as to form a pattern in which the sharp angles along the east side of the Tanganyika line point southward, indicating, under the shearing hypothesis, that the east sides of the Tanganyika faults moved southward with reference to the west sides. Thus, the fault-pattern agrees with displacement-arrows on the diagrams by Willis (Plates 3 and 48). Possibly the faults of the Ubwari trend, being close to the direction of the supposed primary shearing couple, acted as "feeders" of horizontal displacement to the main Tanganyika faults, although their angle with the latter (40°) is greater than observed by the writer in more definite instances of the phenomenon. Faults of this type characteristically are so steep that they could not act as paths of underthrusting. Willis presents no evidence of horizontal displacement along the faults.

An argument that graben blocks descend as mechanical units possibly may be found, by some readers, in the comparative uniformity of the ratio of depth to width of large graben-like depressions, including sea troughs, tabulated by Willis (p. 183). Excluding the more or less circular sea-basins, the table contains 10 major "grabens," 5 of which are sea troughs, and one the Great Valley of California, leaving only 4 typical grabens on land. In the 10 major "grabens" the ratio of width to depth varies only from 1:14 in the Tonga Deep to 1:33 in the Rhine graben. Unfortunately the depths of the 5 sea troughs are measured from sea-level, instead of from the ocean bottom, and hence their ratios in the table are too large, but the required correction would not change their general order of magnitude. If it be true that the depth of a large graben tends even roughly to be proportional to its width, the relationship might mean that the amount of subsidence tends to be roughly proportional to the mass between the graben walls, suggesting that the weight of the "dropped" block may have been a factor in its movement. Even the mere raising of this pertinent question seems strange to geologists who long

have taken it for granted that fault-blocks subside to make grabens. The statement that the amount of subsidence may be roughly proportional to the mass between graben walls involves three questionable assumptions: (1) that unlike hade of the walls of different grabens does not materially affect the size of the body between them; (2) that the density of the material in different graben blocks is essentially constant; and (3) that different grabens met nearly the same resistance to subsidence. Most fatal to the argument is the fact previously mentioned that in some large grabens the gravity anomalies indicate that gravity tends to destroy the grabens, not to create them. In the case of small grabens, early unpublished tabulations by the writer show no relationship whatever between depth and width.

It is impossible to consider here all the problems discussed by Willis. They include an attempt to find ultimate causes of deformation, in which (pp. 77–81, Fig. 4) the melting and expansion of rocks in the deep asthenosphere is postulated as a cause of the uplift of plateaus with marginal grabens. When the reader stops to wonder what could be supposed to have stopped the melting along a straight line, except a pre-existing fault, he will require some other explanation for the origin of the earth's greatest line of rifts.

The make-up of the book is unusually good. It has been well edited in the mechanical way, but needs more references from the text to the maps—a reader may waste much time trying to locate the faults discussed, some of which he will not find on any of the maps.

Errata are rare. The name, L. van Werveke, is misspelled "van Verweke" on p. 5, lines 16, 36, footnote 2; p. 6, line 14, footnote 1; and pp. 347, 358.

In his African field work at the age of 72, Bailey Willis is said to have walked several thousand miles. Doubtless, as usual, he drank each day only a pint or two of water in traversing hot lands where most men need a gallon, a fine sinewy walking machine, "so tough that the cannibals left him alone." That his steps were worthwhile is shown by this book. Yet there is much more back of it, for it is the fruition of a thoughtful life.

CHESTER W. WASHBURNE

149 BROADWAY, NEW YORK
November 14, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

Rochas Oleigenas do Brasil e seu Aproveitamento (Oleagenous Rocks of Brazil and Their Utilization). By S. FRÓES ABREU. 159 pp. (Portuguese with summary of conclusions in English on p. 161), 9 pls. (not numbered, containing 19 photographs and 1 sketch map), 5 figs. (incl. 1 sketch map). Publication not numbered as part of a series. Ministerio do Trabalho, Industria e Commercia, Instituto Nacional de Technologia, Rio de Janeiro (1936).

A better title would have been "Pyrobituminous Sediments of Brazil." The term "oil shale" would not do, for many of the samples described are mere mud, watery algal stúff that, when dried and distilled, yields abundant oil. Few true oil shales are as rich. Considerable theoretical interest attaches also to the discussion of marahunite[1] which Stutzer[2] describes as a "lignitic stage of Boghead coal," an incipient oil shale. Some of the material resembles the "paraffine dirt" of the Gulf Coast.

On the practical side, Abreu considers the possible future value of these and other pyrobituminous sediments in a region of high-priced gasoline. Scores of distillation tests are given, also a discussion of methods of manufacture, and a patriotic plea for the development of this resource. Unfortunately there has been little systematic sampling across the deposits, and few surveys of their thickness and extent.

Like other Brazilian works of this kind, the book is defective in having a poor "index," which in this case is only a one-page table of contents. It suffers also from poor editing, as is seen in the lack of reference marks to tie the inadequate footnotes to the text, in the failure to number plates and figures, in the paucity of maps, *et cetera*. Little attention is paid to the geology of the deposits, in most of which the physiography may be important. The subject matter is largely chemical engineering.

The oil shales of the Iratý formation (Permian), which cover thousands of square miles in southern Brazil, are given only 6 pages, mostly distillation tests. These shales yield mainly heavy unsaturated tars, poor in gasoline. They occur in strata that contain diabase sills, which locally have baked them, a process which possibly may explain the origin of the asphalt that impregnates thick sands in the overlying Triassic. A chemical study of the metamorphism of the Iratý oil shales would be facilitated by the abundant opportunities to observe all stages of the process, at various distances from the igneous intrusions. This should be done.

A peculiar theoretical interest is attached to the proto-oil shales that are now forming in fresh-water ponds by the deposition of algal material. Abreu studied its first stage in an artificial pool in which grew the green alga, *Chlorophycea*, making soft gelatinous masses that contain as much as 92 per cent

[1] Portuguese *Marahuito*, translated into German as *Marahunit*, by Stutzer.

[2] Otto Stutzer, "Marahunit, eine Bogheadkohle im Braunkohlenstadium," *Zeits. Deutsch. Geol. Ges.*, Bd. 87, Heft 9 (1935), pp. 616–20.

water. The oven-dried residue of this material contains more than 50 per cent ash, which consists largely of silicates of alumina and iron. Detailed chemical analysis of the ash (p. 32) and microscopic study indicate that only a negligible part of the ash is composed of rock minerals. The author concludes that it was segregated by the algae, and hence that all the ash (10–20 per cent) found in the more nearly pure algal sediments of Brazil may be organic, rather than detrital. Proximate analysis of the fresh algal material yielded 38 per cent volatile matter and 7.8 per cent fixed carbon, which gives a carbon ratio of 17 per cent, a ratio as high as that of many similar deposits of Pleistocene age.

A gelatinous algal deposit which dries into a rubbery substance of yellow or dark color is forming to-day on the margins of ponds, and is said to cover a large part of the ground surface in low depressions, from which one may infer that only in the wet season need it be covered by water. The closely related algal substance, marahunite, in beds a meter or more thick, occurs interbedded with Pleistocene and Recent stream and lake sediments. Nine beds of it, ranging from 0.38 to 10.75 meters thick, and totalling 32.20 meters (105.6 feet), are reported interstratified with Pleistocene(?) clays and sands in the upper 91.42 meters (300 feet) of a prospect well at Marahú, Bahia. Unfortunately there are no chemical analyses of the marahunite from this well, or of any other deeply buried marahunite; hence, we do not know the chemical change it undergoes under deep burial or during long time. A suggestion that the change may be small appears in the lack of decided increase in the carbon ratio of Pleistocene marahunite over that forming to-day.

After being dried in an oven, marahunite that originally contained 60 per cent water loses the capacity of absorbing more than a trace of water. The author, following Stutzer, believes that this is caused by the deposition of wax on the particles (largely colloidal) of the algal débris. Under the microscope the algal matter is seen to form light-colored translucent bodies embedded in a dark humic groundmass. The light-colored marahunite is richer than the dark, picked samples of it yielding as high as 577 liters (165 gallons) of crude oil per metric ton. A general average of all samples is 250 liters (71.5 gallons) per metric ton. Most of the oil distilled was created by the pyrolysis of the algal, rather than of the humic component.

The lighter-colored marahunite, dried in air, has the lower density (0.52–0.97 in 7 samples, mean 0.74), as compared with the darker marahunite (density 0.96–1.29 in 3 samples, mean 1.13). A few calculations by the reviewer indicate that the carbon ratio of the light variety is slightly less than that of the dark. Light, as well as dark varieties, occur in both Recent and Pleistocene deposits, and the author does not mention any tendency of the material to grow darker with age. Abreu believes that the dark variety is formed from the light variety by oxidation, although from one locality a light-colored sample (p. 77) contains less oxygen than a dark-colored one (p. 78). Possibly the oxidation consists mainly in the removal of hydrogen as water, rather than in fixation of oxygen in organic compounds. Percentage of organic acids is not given. Marsh fires turn the material dark, even black, being presumably not hot enough to burn it. Marahunite is insoluble in "petroleum ether" (density 0.64), but is attacked by solutions of *NaOH* and *KOH*, from which *HCl* precipitates humic compounds. Chloroform dissolves 30.7 per cent of the dark variety, but much less of the light-colored variety, the solute being a dark "mountain wax" that melts at 50°C., and is partly soluble in benzine.

The valley of the Rio Parahyba do Sul, which is followed by the highway and railroad between São Paulo and Rio de Janeiro, was found by the reviewer[3] to be a Pleistocene fault block, initiated possibly in the late Tertiary, tilted northwestward toward the master fault along that side of the valley, which is partly filled with fluviatile and lacustrine sediments that contain a flora and fauna of rather modern aspect. Smith Woodward thought that the fish are late Tertiary. Inasmuch as the sediments in question are among the youngest in the valley, and the physiography of the region indicates that the main movement on the fault that determines the valley occurred in the Pleistocene, the reviewer suspects that the interbedded oil shales are not older than the Pleistocene. At two localities in the valley, Caçapava and Floriano, Abreu admits that the oil shales are Pleistocene or Recent, but he follows the general custom of assigning Tertiary age to a third locality in the valley, Trembembé. The physiographic evidence that they are not so old possibly may be supported by their slight degree of metamorphism, for in 4 analyses (p. 99) of Trembembé oil shales, the carbon ratios are only 8.5–21.9 per cent, mean 14.9 per cent, some of these figures being less than the carbon ratio, 17 per cent, of the algal jelly forming to-day in Abreu's experimental tank. I. C. White[4] gives a proximate analysis of Trembembé oil shale, from which the reviewer calculates a carbon ratio of 21 per cent. He reported that beds of oil shale, intercalated with clays and sands, extend to the bottom of a test well 150 meters (492 feet) deep. Abreu gives no carbon ratios, all of those mentioned here having been calculated by the reviewer in an attempt to discover indications of metamorphism.

Regardless of the possible economic value of the Brazilian algal deposits and other pyrobituminous sediments, those now forming in fresh-water ponds and the related geologically young deposits have great scientific interest. In these ponds there is abundant life, fish, mollusca, ostracods, fresh-water sponges and bacteria of many kinds. The tropical climate and other conditions evidently promote algal life more than decomposition, in spite of the absence of preservative salts, for in some ponds beds of algal material have accumulated to a thickness of 1–3 meters. The amount and the nature of the decomposition and other features of the algal deposits will make interesting study, and one appreciates, the groundwork for it in this report by Abreu.

CHESTER W. WASHBURNE

149 BROADWAY, NEW YORK
November 22, 1936

"Het Palacogeen in den Indischen Archipel" (The Paleogene of the Malay Archipelago). By H. H. BADINGS. *Verhandelingen van het Geologisch-Mijnbouwkundig Genootschap voor Nederland en Koloniën*, Geol. Ser., Deel XI (1936), pp. 233–99.

This paper belongs to a series of recent contributions devoted to summarizing the available data on the stratigraphy and paleogeography of the Dutch

[3] C. W. Washburne, "Petroleum Geology of the State of São Paulo, Brazil," *Commissão Geog. e Geol. do Estado de São Paulo Boletim 22* (1930), pp. 83, 92, 116, and Structural Index Map, Plate II. The tables of carbon ratios in this report are worthless, because of typographic errors.

[4] Cited by Abreu, p. 100. I. C. White, *Relatorio Final* (1908). Commissão dos Estudos das Minas de Carvão de Pedra do Brasil, Ministro da Industria, Viação e Obras Publicas, Rio de Janeiro.

East Indies. In order to understand its scope, a few words on the "letter classification" of the East Indian Tertiary may be helpful. The Paleogene (Eocene and Oligocene) are divided into Tertiary *a*, *b*, *c*, and *d*; and Neogene (Miocene and Pliocene) into Tertiary *e*, *f*, *g*, and *h*. The several divisions of the Paleogene are paleontologically defined by their content of nummulites and orbitoids. Tertiary *a* and *b* belong, at least approximately, to the Eocene of other lands, Tertiary *c* and *d* to the Oligocene.

Badings makes effective use of some paleogeographic maps, one each for Tertiary *a*, *b*, *c*, and *d*. Each one shows not only the distribution of land and sea during the period it represents, but also the occurrence of littoral, neritic, and freshwater deposits. Even more helpful to the reader is the presence on each map of a figure for each locality—200 of them altogether—that is mentioned in the text. The numbers are arranged to follow the order of discussion in the text. On page 235, for example, in the discussion of Sumatra, the Oembiling region is mentioned, the word being followed by a figure 1 in parenthesis. This figure is readily discovered on the map, near the middle of the western coast of Sumatra. On page 281 a paragraph is devoted to "the small islet Miangas (200)," which may likewise be located with equal ease between Mindanao and the Moluccas.

Badings' conclusions as to Paleogene paleogeography are briefly: (1) that the Malay Peninsula extended far to the southeast, so as to embrace much of the present Sunda Shelf, Sumatra, and part of Borneo; (2) that Australia extended north to include most of the Sahul Shelf and part of New Guinea; and (3) that the intervening areas, so far as they may be studied, consisted of islands and shallow seas, which changed their form from time to time. Thus, Dutch Timor was a region of neritic sedimentation during Tertiary *a* and *b*, but is shown as land during Tertiary *c* and *d*. The north arm of Celebes, on the other hand, was land during all stages of the Paleogene, and a large area in east-central Borneo was continuously submerged.

The paper includes generalized sections of Paleogene strata for many localities, and shows their relations to overlying and underlying formations. The unconformities are indicated graphically in the sections, and their character and distribution are also displayed on two maps. A discordance between Cretaceous and Tertiary is known or inferred to exist over much of the Archipelago. In only two localities, central Celebes and a locality in the Tanimber Islands, is concordance indicated as probable. Tertiary *a* and *b* are discordant in two localities in northern Sumatra, Tertiary *c* and *d* in parts of northeastern Borneo. There is a widespread discordance between Neogene and Paleogene, Tertiary e_3 being in many localities the transgressive member. This stage belongs approximately to the Middle Miocene, and the transgression recorded by it is often called the Bebulu transgression. Badings believes that it is represented even on Christmas Island in the Indian Ocean.

The paper concludes with a bibliography of 199 titles and a table of contents.

R. D. REED

LOS ANGELES, CALIFORNIA
December 7, 1936

"Extent and Availability of Natural Gas Reserves in Michigan 'Stray' Sandstone Horizon of Central Michigan." By E. L. RAWLINS AND M. A. SCHELLHARDT. *U. S. Bur. Mines Repl. Investigations 3313* (July, 1936).

Printed by the Michigan Department of Conservation in coöperation with the Michigan Public Utilities Commission.

The authors are well known engineers of the United States Bureau of Mines. They perfected the back-pressure method for taking open-flow tests and have written a bulletin on the subject. The senior author made a report on the "Gas Reserves of the Oklahoma City Pool." Their present study should be of interest to geologists because of the structural maps and well data which are included. A map showing the areal geology of the Southern Peninsula of Michigan, by Helen M. Martin, is published in this report for the first time.

The geological interpretations were made by the State Geological Survey and this report should be considered supplementary to "Oil and Gas Fields of Michigan," publication No. 38, by R. B. Newcombe, issued in 1933.

The Stray gas sand occurs in the Grand Rapids series of Mississippian age, at depths ranging from 1,000 to 1,400 feet. The Grand Rapids series was deposited on an uneven surface. Locally, near the base of the series, reworked Marshall was deposited as the "Stray" sand, possibly as an off-shore bar. This sand varies from 2 to 29 feet in thickness, separated by thin shale beds.

Oil and gas development in Michigan is relatively recent, the first wells, at Muskegon, being drilled in 1927. Gas has been encountered in the shallow Stray sand in many areas where deeper tests have been drilled for oil. In the past 3 years gas fields have been developed which have made it increasingly important to have accurate information in regard to reserves, so that this natural resource might be utilized.

Initial open-flow productions, though variable, have been as high as 50 million cubic feet per day. The principal constituents of the gas are methane and ethane, with an average heating value of 1,050 B.T.U. per cubic foot. Pressures are normal for the depths drilled, being approximately 500 pounds per square inch absolute.

Attention should be called particularly to the basic formula used in estimating reserves, which is outlined on page 7.

The largest single area of Stray gas development to date is described by the authors as Hinton-Milbrook-Belvidere. This area is sometimes called Six Lakes. It has had consistent development during the past year and recent drilling there has shown a thickness of sand in some wells greater than previously reported. About 10,000 acres have been proved by drilling in the Six Lakes area. The seven gas pools studied have a total producing area of 30,000 acres. The estimated future recoverable reserve, based on an abandonment pressure of 15 pounds per square inch absolute is 53 billion cubic feet.

The Central Michigan Basin is still under active development and it is reasonably certain that other gas pools will be discovered which will add to this reserve.

This report, which establishes methods of measurement and sets up reserves for the fields so far developed, should be regarded as a thorough study by experienced engineers. Their estimated reserves appear to be very conservative.

THERON WASSON

CHICAGO, ILLINOIS
November 6 1936

RECENT PUBLICATIONS

ASIA

*"Central Asia in Cretaceous Time," by Frederick K. Morris. *Bull. Geol. Soc. America* (New York), Vol. 47, No. 9 (September 30, 1936), pp. 1477–1534; 5 figs., 2 pls.

BRAZIL

*"Paleontologia de parte superior do Grupo Estrada Nova" (Paleontology of the Upper Part of the Estrada Nova Group), by Aristomenes G. Duarte. *Mineração e Metallurgia* (Rio de Janeiro, Brazil), Vol. 1, No. 1 (May–June, 1936), pp. 6–8; 1 fig.

*"Contribuição ao conhecimento das formações pré-devoneanas no Brasil" (Contribution to the Knowledge of the Pre-Devonian Formations of Brazil), by Octavio Barbosa. *Ibid.*, pp. 21–23.

*"Possibilidades da existencia de petroleo em Alagôas" (Petroleum Possibilities in Alagôas) by Victor Oppenheim. *Ibid.*, pp. 26–32; 7 figs.

CALIFORNIA

*"The Pleistocene Fauna of Magdalena Bay, Lower California," by Eric Knight Jordan. Introduction by Leo George Hertlein. *Contrib. Dept. Geol. Stanford University* (Stanford University, California), Vol. 1, No. 4 (November 13, 1936). 173 pp. Price: paper, $1.25; cloth, $2.00.

DUTCH EAST INDIES

*"Heterospira, A New Foraminiferal Genus from the Tertiary of Borneo," by J. H. F. Umbgrove. *Leidsche Geol. Mededeelingen* (Leiden, Holland), Deel VIII, Aflevering 1, VII (1936), pp. 155–60; 11 figs.

ENGLAND

*"The Structure of the Eocene Outlier Near Knockmill, Kent," by Raymond H. Chandler and Arthur L. Leach. *Proc. Geol. Assoc.* (London), Vol. 47, Part 3 (1936), pp. 239–48; 5 figs.

*"The Upper Jurassic Rocks of the Country Between Malton and Castle Howard, East Yorkshire," by Vernon Wilson. *Ibid.*, pp. 254–64; 2 illus.

FLORIDA

"Artesian Water in the Florida Peninsula," by V. T. Stringfield. *U. S. Geol. Survey Water-Supply Paper 773-C* (1936), pp. 115–95, Pls. 6–16 (incl. maps), Figs. 10–18. For sale by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.20.

FRANCE

"Le pétrole en Languedoc" (Petroleum in Languedoc), by Georges Vié. *Pierres et Minerais* (Paris and Bruxelles-Forest), April, 1936. 2 pp., 1 map.

*"Découverte d'horizons pétrolifères jurassiques et triasiques à Pechelbronn" (Discovery of Jurassic and Triassic Petroliferous Horizons in Pechelbronn), by Ch. Finaton. *La Revue Petrol.* (Paris), No. 706 (October 25, 1936), pp. 1573–77; 6 figs.

GENERAL

"The Geologic Time Classification of the United States Geological Survey Compared with Other Classifications, Accompanied by the Original Definitions of Era, Period, and Epoch Terms, a Compilation," by M. G. Wilmarth. *U. S. Geol. Survey Bull. 769* (1925; reprint, 1936). 138 pp., 1 pl. For sale by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.25.

*"Aerial Geologizing." *Amer. Inst. Min. Met. Eng.* (New York), *Tech. Pub. 756* (1936). 27 pp. Includes "Aerial Reconnaissance and Contour Mapping in Mining," by Leon T. Eliel, 17 pp., 10 figs.; and "Development of Aerial Photographic Equipment," by William H. Meyer, Jr., 5 pp.

*"Mid-Continental Diastrophism in Late Paleozoic Times," by Charles Keyes. *Pan-American Geol.* (Des Moines, Iowa), Vol. 66, No. 4 (November, 1936), pp. 279–306; 6 figs., 1 table.

*"Structure of the Earth's Crust and the Spreading of the Continents," by Beno Gutenberg. *Bull. Geol. Soc. America* (New York), Vol. 47, No. 10 (October 31, 1936), pp. 1587–1610; 2 figs.

*"Fauna of the Pleistocene Pamlico Formations of the Southern Atlantic Coastal Plain," by Horace G. Richards. *Ibid.*, pp. 1611–56; 1 fig., 4 pls.

*"Recent Developments Related to Petroleum Engineering," by Joseph Jensen. *California Oil World* (Los Angeles), Vol. 29, No. 12 (October 8, 1936), pp. 8, 18–20.

*"Revision of the Genus Calapoecia Billings," by Ian Cox. *National Mus. Canada* (Ottawa) *Bull. 80* (1936). 49 pp., 1 fig., 4 pls. (including 30 figs.). Price, $0.25.

*"Heutige Meeresablagerungen als Grundlagen der Beurteilung der Ölmuttergesteins-Frage" (Present Marine Deposits as a Basis for Consideration of the Problem of Petroleum Source Rocks), by Karl Krejci-Graf. *Petrol. Zeit.* (Wien), Vol. 32, No. 44 (November 4, 1936), pp. 12–18.

*"Means of Recognizing Source Beds," by Parker D. Trask and H. Whitman Patnode. Part I, *California Oil World and Petrol. Indus.* (Los Angeles), Vol. 29, No. 20 (December 3, 1936), pp. 8–12; 3 figs., 2 tables. Part II, *ibid.*, No. 21 (December 10, 1936), pp. 6–9; 7 figs., 1 table.

*"Notes on the Mechanism of Folding," by L. U. de Sitter. *Leidsche Geol. Mededeelingen* (Leiden), Deel VIII, Aflevering 1, VII (1936), pp. 161–68; 4 figs.

*"Evaluation of Oil Lands During Exploration," by Clarence P. Dunbar and V. G. Gabriel. *Oil Weekly* (Houston), Vol. 83, No. 13 (December 7, 1936), pp. 49–50, 52; 4 tables.

GEOPHYSICS

*"Progress in Magnetometer Exploration Leads to Resurvey of Many Areas," by James A. Dick. *California Oil World* (Los Angeles), Vol. 29, No. 15 (October 29, 1936), pp. 7–8; 5 illus.

*"Gravity Anomalies in the United States," by E. A. Glennie. *Jour. Geol.* (Chicago), Vol. 44, No. 7 (October-November, 1936), pp. 765–82; 4 figs., 4 tables.

*"Bibliography of Seismology," by Ernest A. Hodgson. *Pub. Dominion Observatory* (Ottawa), Vol. 12, Nos. 10 and 11 (April-September, 1936). Price, 25 and 35 cents, respectively.

GULF COAST

*"Petrographic and Physical Characteristics of Sands from Seven Gulf Coast Producing Horizons," by M. T. Halbouty. *Oil Weekly* (Houston), Vol. 83, No. 11 (November 23, 1936), pp. 21–24; 1 illus., 1 table; No. 12 (November 30, 1936), pp. 22, 24, 26; 1 table; No. 13 (December 7, 1936), pp. 36–38, 40, 42, 44, 46, 48; 48 figs. (histograms), 1 table; No. 14 (December 14, 1936), pp. 34–50; 48 figs. (32 histograms and 16 photomicrographs).

ILLINOIS

*"Possibilities for Oil Production in the Illinois Basin," by W. V. Howard. *Oil and Gas Jour.* (Tulsa), Vol. 35, No. 26 (November 12, 1936), pp. 76, 78, 80, 195; 3 figs., 1 table.

INDIA

*"Geology and Economic Significance of Burma Oil Fields," by Dudley Stamp. *World Petroleum* (New York), Vol. 7, No. 11 (November, 1936), pp. 580–92; 13 illus.

ITALY

*"La géologie de la Vallée supérieure du Serio" (The Geology of the Upper Valley of the Serio), by J. Weeda. *Leidsche Geol. Mededeelingen* (Leiden), Deel VIII, Aflevering 1, VII (1936), pp. 1–54; 11 figs., 4 pls.

LOUISIANA

*"Potential Structures in North Louisiana," by Mitchell Tucker. *Oil and Gas Jour.* (Special Rodessa Number) (Tulsa), Vol. 35, No. 22 (October 15, 1936), pp. 66–67, 100; 5 illus.

*"North Louisiana Stratigraphy Gradually Being Worked Out," by A. F. Crider. *Ibid.*, pp. 74, 88, 90, 95, 96; 4 illus.

*"Intensive Seismic Exploration in North Louisiana District," by Josiah Taylor. *Ibid.*, pp. 79, 82; 6 illus.

*"Economic Importance of the Sabine Uplift—An Outline," by H. D. Easton. *Ibid.*, Vol. 35, No. 28 (November 26, 1936), pp. 22–24, 34; 4 illus.

MARYLAND

*"Age Reclassification of the Frederick Valley (Maryland) Limestones," by Anna I. Jonas and George W. Stose. *Bull. Geol. Soc. America* (New York), Vol. 47, No. 10 (October 31, 1936), pp. 1657–74; 7 figs.

NEW MEXICO

*"Geology and Fuel Resources of the Southern Part of the San Juan Basin, New Mexico: Part 2, The Mount Taylor Coal Field," by C. B. Hunt. *U. S. Geol. Survey Bull. 860-B* (1936), pp. 31–80, Pls. 18–38, Figs. 1–2. For sale by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $1.00.

"A Reconnaissance and Elevation Map of Southeastern New Mexico," by Walter B. Lang. Scale, 1:190,080. Approx. 30×60 inches.

"Oil and Gas Map of New Mexico" (included in "The Oil and Gas Resources of New Mexico," by Dean E. Winchester, *Bull. 9*) revised to July 15, 1936, by A. Andreas. *State Bur. Mines and Min. Res., New Mexico School*

Mines (Socorro). Scale, 1:1,000,000 or approximately 1 inch:16 miles. Map shows axes of nearly 200 anticlinal structures and location, total depth, and results (by symbol) of approximately 1,200 wildcat wells. Known oil and gas fields are indicated and location of main oil and gas pipe lines, refineries, and natural gasoline plants are shown. Carbon dioxide gas areas indicated.

NEW YORK

*"The Clinton in New York," by John T. Sanford. *Jour. Geol.* (Chicago) Vol. 44, No. 7 (October–November, 1936), pp. 797–814; 2 figs., 3 tables.

*"Eastern New York Ordovician Cherts," by Rudolf Ruedemann and T. Y. Wilson. *Bull. Geol. Soc. America* (New York), Vol. 47, No. 10 (October 31, 1936), pp. 1535–86; 2 figs., 7 pls.

ROUMANIA

*"Une decoverte de la geophysique francaise" (A French Geophysical Discovery). *La Revue Petrolifere* (Paris), No. 702 (September 26, 1936), pp. 1445–47; 2 maps (resistivity map of Bucsani region made by Schlumberger methods; isobathic map showing Pontien-Meotic contact).

RUSSIA

*"The Conditions of Accumulation of Natural Gas in the Earth's Crust and Their Bearing upon Various Parts of Geological Science," by A. L. Koslov. *Problems of Soviet Geology* (Moscow), Vol. 6, No. 8 (1936), pp. 656–75; 3 figs. In Russian.

*"Sedimentation and Facies of the Paleozoic Deposits of Samarskaya Luka," by K. B. Ashirov. *Ibid.*, pp. 693–703. In Russian.

*"The First Stages of the Development of the Kasan Sea in the Northern Part of the Russian Platform," by J. D. Sekkel. *Ibid.*, pp. 704–11. In Russian.

*"Contributions to the Question of the Location of Deep Wells in the European Part of the U. S. S. R.," by M. S. Shvetzov. *Ibid.*, pp. 712–13. In Russian.

*"The Devonian of the Salair," by P. S. Lasutkin, D. V. Nalivkin, M. A. Rzhonsnitskaya, and V. J. Yavorsky. *Ibid.*, pp. 719–26. In Russian.

*"Determinations of Dip and Strike of Rocks by Means of Inclined Bore-Holes," by G. Voynovsky-Kriger. *Ibid.*, pp. 727–35; 7 figs. In Russian.

*"Ostracoda of the Koltchuglno Series of the Kusnetsk Coal Basin" (paper reviewed by author), by D. N. Spizharsky. *Ibid.*, p. 736. In Russian.

*"The Plants from the Limit of Carboniferous and Permian in the Donetsk Basin" (review), by M. D. Zalessky and E. F. Chirkova. *Ibid.*, p. 736. In Russian.

*"A Stratigraphic Outline of the Ishimbaev Limestones Based upon a Study of the Fusulinid Fauna," by D. F. Shamov, I. D. Korzhnevsky, and A. Y. Vissarionova. *Ibid.*, Vol. 6, No. 9 (1936), pp. 815–31; 2 tables. In Russian.

*"The Main Ural Reef-Limestones Bryozoa on the Boundary of the Permian and the Carboniferous Formations," by A. I. Nikiferov. *Ibid.*, pp. 838–39. In Russian.

SPAIN

*"Die geologie von Camarena de la Sierra und Riodeva (Provinz Teruel, Spanien)" (The Geology of Camarena de la Sierra and Riodeva, Province of

Teruel, Spain), by R. Martin. *Leidsche Geol. Mededeelingen* (Leiden), Deel VIII, Aflevering 1, VII (1936), pp. 55–154; 34 figs., 2 pls.

TENNESSEE

*"The Flynn Creek Disturbance, Jackson County, Tennessee," by Charles W. Wilson, Jr. *Jour. Geol.* (Chicago), Vol. 44, No. 7 (October–November, 1936), pp. 815–35; 9 figs.

TEXAS

"Petroleum Engineering Study of the Big Spring Field and Other Fields in West Texas and Southeastern New Mexico," by Charles B. Carpenter and H. B. Hill. *U. S. Bur. Mines Rept. Invest. 3315* (1936). 223 pp., 40 illus. Published through coöperative assistance of the Midland, Texas, Chamber of Commerce. Available from Information Division, U. S. Bureau of Mines, Washington, D. C., or Chamber of Commerce, Midland, Texas.

TURKEY

*"Etütler: Van gölü civarinda korzot petrolü" (Oil at Korzot near Lake Van), by Cevat Eyüb Taşman. *Maden Tetkik ve Arama*, Enstitüsü Yayini (Ankara, Turkey), Sayi 5 (29 1^ei^ Teşrin, 1936), pp. 41–44; 1 illus. In Turkish and in English.

WYOMING-UTAH-COLORADO

"Geomorphology of the North Flank of the Uinta Mountains," by W. H. Bradley. *U. S. Geol. Survey Prof. Paper 185-I* (1936), pp. 163–204, Pls. 34–45, Figs. 11–24. For sale by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.45.

Courtesy, Los Angeles County Chamber of Commerce

Alamitos Bay, Long Beach, Los Angeles County, California, (Come to the A.A.P.G. annual meeting, Los Angeles, March 17–19, 1937).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 1 (JANUARY, 1937), PP. 130-134, 1 FIG.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Hans Ashauer, Los Angeles, Calif.
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Wilbur Frank Cloud, Norman, Okla.
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SECOND WORLD PETROLEUM CONGRESS
PARIS, JUNE 14–19, 1937

The second World Petroleum Congress will be held in Paris, June 14–19, inclusive, 1937. The officers of the organization committee are: (1) honorary president, L. Pineau, honorary president of the Association Française des Techniciens du Pétrole, and director of the Office National des Combustibles Liquides; (2) president, Ch. Bihoreau, former president, Association Française des Techniciens du Pétrole, and director of the Technical Bureau of the O.N.C.L.; and (3) general secretary, J. Filhol, general secretary of the Association Française des Techniciens du Pétrole, and chief of the Information Bureau of the O.N.C.L.

The work of the Congress has been divided into the five following sections: (1) Geophysics and Exploitation, (2) Physics, Chemistry, and Refining, (3) Materials and Construction, (4) Utilization of Petroleum Products, and (5) Economics and Statistics.

It is expected that papers on the following subjects will be presented in the Section of Geology and Exploitation.

A. Geological descriptions of petroliferous regions

B. Methods of geological prospecting
   1. Practical working methods on the ground: equipment, utilization of airplanes (aerial survey), exploration drilling, study of cores in the fields—water, gas, and various products
   2. Working methods in laboratory: study of the different drilling muds, formations, and heavy minerals; geological control of drilling; water and gas analysis, *et cetera*
   3. Synthetic study of crude petroleum, characteristics, and formation

C. Modern improvement in drilling equipment: deep-drilling, directional or inclined drilling, drilling muds, composition, use. Improvements in exploitation methods: spacing of wells, control of gushers, adaptation of methods to local conditions, rejuvenation of oil fields

D. Geophysics
   1. Technical developments since 1933 (date of the last Congress in London) in the different methods of prospecting; seismic gravity; electricity, magnetism, electrical cores, *et cetera*
   2. Legal status: legal value in the various countries of geophysics in respect to the petroleum mining rights, and general mining rights

The American Association of Petroleum Geologists has accepted the invitation of the organization committee to be responsible for the preparation of papers descriptive of recent progress in the United States as outlined in the program for the Section of Geology and Exploitation. President R. D. Reed

has appointed Winthrop P. Haynes, of the Standard Oil Company of New Jersey, 30 Rockefeller Plaza, New York City, as chairman of a committee to secure manuscripts. Those who desire to attend the Congress or to submit papers may communicate with chairman Haynes in New York, with Association headquarters in Tulsa, Oklahoma, or with the Secrétariat Général du Congrès, 85 Boulevard du Montparnasse, Paris (6e), for special information.

Papers of general interest are desired, even if they do not come under the headings listed in the announcement. Manuscripts should be received by February 1, 1937.

French will be the official language of the Congress, but communications may be submitted in English or German.

The registration fee is 50 francs.

Before the Congress, excursions are planned to (1) Morocco for one week and (2) southern France to visit the Cote d'Azur.

After the Congress, three trips are planned to (1) the refineries of the Basse-Seine, including an excursion in Normandie (Rouen, Le Havre, Trouville, Deauville, Swiss-Normandy); (2) plants in the northern part of France including excursions in the Artois and at Notre-Dame-de-Lorette; and (3) oil fields and refineries of Pechelbronn, and domanial mines of potassium, followed by excursions to Nancy, Strasbourg, and through the Vosges.

TWENTY-SECOND ANNUAL MEETING, LOS ANGELES MARCH 17, 18, 19, 1937

Members of the Pacific Section are at work and are determined to provide a convention program and setting that will in all respects justify the effort of journeying the additional miles westward from our geographical center.

It is believed that many members will desire to take a little longer than usual in their visit to Southern California and, for this reason, the convention committees are planning an entertainment schedule running from Monday, March 15, to Saturday, March 20.

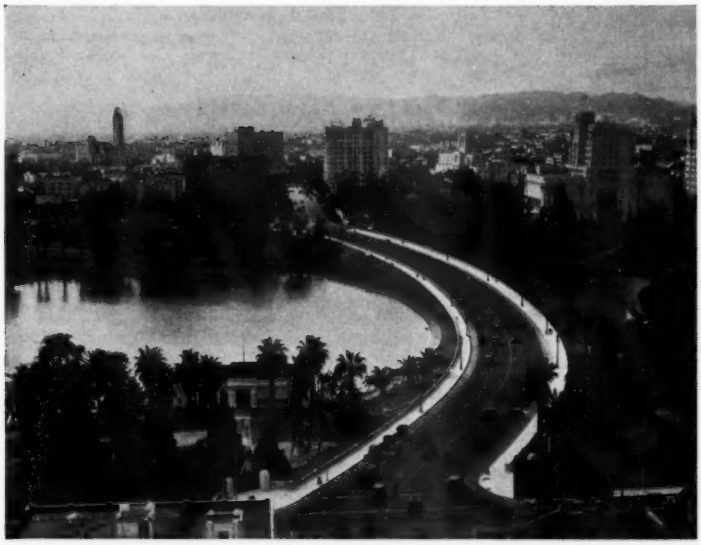
The principal entertainment will include a flexible series of field trips, covering points in the Los Angeles Basin and the more distant districts of Ventura and Santa Barbara counties and the San Joaquin Valley. In addition, a complete sightseeing schedule covering points of general interest in and around Los Angeles and Hollywood is being planned for visiting members and their ladies.

A further objective of the committee is to provide reasonably priced accommodations for all visitors who may so desire in the headquarters hotel. This hotel, the Los Angeles Biltmore, is large enough to accommodate comfortably the entire convention, with adequate space for all meetings and desirable rooms for all visitors. Further details in this connection will reach all members at an early date.

The technical program on the 17th, 18th, and 19th is being designed to include papers of broad general interest. Many papers are yet to be definitely assigned, particularly those of economic and historic interest involving California. At the time of going to press the following papers appear on the program.

KANSAS	
E. A. Koester and J. I. Daniels	Regional paper on the Geology of Kansas
G. W. Baughman and Marvin Lee	Symposium—Recent Developments
ROCKY MOUNTAIN REGION	
R. L. Heaton	Relation between Stratigraphy and Structure as Regards Oil Accumulation
Harry Osborne and W. O. Thompson	Geology of the Front Range and Adjoining Region
TEXAS (EXCEPT WEST TEXAS)	
E. G. Thompson	Fault System of Northeast Texas with Emphasis on the Talco Structure as a Type
Herschel H. Cooper	Occurrence and Accumulation of Oil in the Laredo District of Texas
P. F. Martyn	Geology of the Refugio Field, Texas
LOUISIANA AND ARKANSAS	
Max Bornhauser	Geology of the Tepetate Field, Louisiana
WEST TEXAS	
E. R. Lloyd	Geology of the West Texas Permian
CALIFORNIA	
W. P. Woodring	Paleogeographic Implications of Larger Fossils from the Repetto Formation of the Los Angeles Basin

FRANK A. MORGAN



Courtesy, Los Angeles County Chamber of Commerce

Wilshire Boulevard through West Lake Park, looking west; Wilshire district and Hollywood in background.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 1 (JANUARY, 1937), PP. 135-141, 3 FIGS.

Memorial

DEAN EDDY WINCHESTER
(1883–1936)

Dean Eddy Winchester, State Supervisor of the Works Progress Administration investigation of mineral resources of Colorado, died at Eads, Colorado, August 31, 1936, after an emergency appendectomy. He was born at Gibbon, Nebraska, June 29, 1883. He is survived by his wife, Bertha Greene Winchester, and three children, Herbert Eddy, Jessie Louise, and Norman Carl. The family resides at 784 Garfield Street, Denver, Colorado.

Winchester acquired his education in Nebraska schools, and prepared himself for his life work in geology at the University of Nebraska, from which he graduated in 1907. After graduation, he became a member of the United States Geological Survey, and continued with that organization until 1920. During his years with the Geological Survey, he made extensive investigations of water, coal, oil, and oil-shale resources in various parts of the United States, and published the results of these studies in numerous bulletins. He was a pioneer in the investigation of the oil-shale deposits of the West, and his maps and texts published by the Geological Survey, as well as his several articles in trade and technical publications, formed the basis for much subsequent investigation by private interests.

In 1919, he obtained temporary leave of absence from the Geological Survey, and made an examination of coal, petroleum, and oil-shale deposits in the West Indies, for Richmond, Levering and Company. Soon after his return to the United States and the completion of that work, he terminated his connection with the Geological Survey, and from 1920 to 1922 engaged in a series of geologic studies in South America and the United States, first for Lewis Emery, Jr., and later for the Carter Oil Company and the Standard Oil Company (New Jersey).

He soon determined that neither foreign work nor the routine of company employment were particularly attractive to him, and in 1922 he undertook the practice of geology in a consulting capacity, locating in Denver, Colorado, where he maintained his office until his death. During this period, he continued his interest and studies in oil, gas, and oil-shale geology, largely devoting his time to areas in the Rocky Mountain region. He was particularly interested in oil and gas possibilities in New Mexico and devoted much time to the study of that area. In 1933, after an extensive field and office study, he completed a report entitled "The Oil and Gas Resources of New Mexico," a volume which has proved most helpful as a reference work.

Through the persistent efforts of Mr. Winchester the Colorado State Planning Commission was able to secure a W.P.A. Project to aid the mining and petroleum industries of the state. The nature of this work was to collect all unpublished information possible on Colorado's mineral resources. Under his direction this project has gathered together much valuable information on underground water, metal mines, non-metallic resources, and petroleum. His idea was to place this collected material in the Denver Public Library where it would be available for all those interested. The success of this project was

DEAN EDDY WINCHESTER

due to Mr. Winchester's high standing in the engineering and geologic professions, and his wide knowledge of Colorado's mineral resources.

He was a member of the American Institute of Mining and Metallurgical Engineers, American Association of Petroleum Geologists, Geological Society of Washington, and was president of the Rocky Mountain Association of Petroleum Geologists for one year.

His earnest, straight-forward nature, tempered with a quiet sense of humor, gained for him the friendship and respect of all who knew him. He leaves a host of friends in Colorado and elsewhere to whom his death comes as a distinct loss.

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W. B. EMERY

CASPER, WYOMING
November 17, 1936

FRANÇOIS BIRAUD

FRANÇOIS BIRAUD
(1899–1936)

The accidental death of François Biraud, which occurred in Djeddha, Arabia, on July 13, 1936, was a loss felt particularly by the French petroleum geologists.

Biraud was born on September 13, 1899, in Pauillac, Gironde. After a complete course of study in the Lycee de Poitiers, he passed his examinations, received his two baccalaureates, and planned to study medicine. However, he was interrupted in his work, at first by an illness, and then by military obligations.

With his professors' advice, he gave up his medical studies and came to Paris for scientific pursuits. He successively got the physics-chemistry-natural history, botany, zoology, geology, physical-geography certificates which guaranteed him a very complete knowledge of geologic sciences.

At the end of 1926, Biraud became a geologist with the Iraq Petroleum Company until October, 1932. During these 6 years, he undertook much work in various Iraq countries, sometimes in reconnaissance exploration, sometimes in more exacting studies which allowed him to examine one after the other the rocky countries of Kurdistan and the desert zones of the Tigris and the Euphrates.

In 1932, he returned to France, was married, and joined the Compagnie Française des Petroles. He was chiefly employed with matters concerning petroleum research in French Colonies.

In Paris, he specialized in laboratory work on heavy minerals. He obtained in this difficult branch very good results, and organized the employment of these methods in Madagascar and in Equatorial Africa.

Apart from these works, Biraud studied the geology of Tunisia and Algeria in 1934 and 1935, and was able to show in these difficult countries all his qualities of observation.

In 1936, at last, Biraud was sent on a mission in Arabia and it is here that an accident removed him from his family's and friends' affection.

In the course of a career, short alas! but well filled, Biraud gave the full measure of his technical qualities which won the approval of his chiefs. However, apart from his scientific knowledge, Biraud had the affection of all those who approached him, by his manly figure, his good temper, his fairness and frankness of mind. He left many friends, not only in France, but among his English colleagues, too.

He was a member of the American Association of Petroleum Geologists since 1931 and a member of the Association Française des Techniciens du Pétrole.

H. DE CIZANCOURT

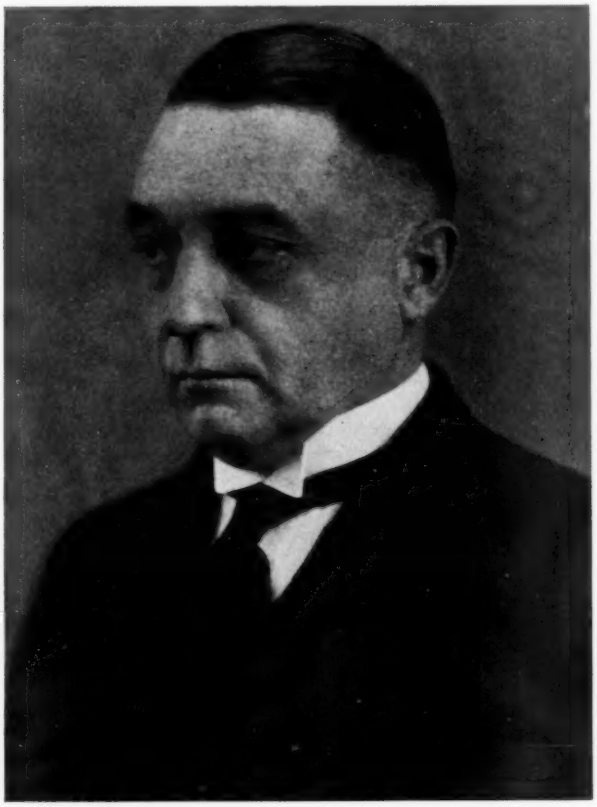
PARIS, FRANCE
October 23, 1936

OTTO STUTZER
(1881–1936)

In the sudden death of Professor Dr. Otto Stutzer on September 29, 1936, was lost one of the most widely known and versatile geologists of this generation. He was a man of indefatigable energy who made important contributions in many fields of geology and contributed to the propagation of the science both in its literature and through geological organizations.

Dr. Stutzer was born in Bonn on May 20, 1881, the son of Professor Albert Stutzer. He pursued his university training in Königsburg, Munich, Tübingen, and Heidelberg, receiving his doctor's degree at Tübingen in 1904, and completing his Oberlehrer examination at Königsburg in 1905. On April 1, 1905, he became assistant to Professor Richard Beck at the Freiberg School of Mines. At that time he was a quick alert young man of slender build who was very popular with the students. By 1913 he had risen to the rank of ausserordentliche professor. In the meantime he had spent a year, 1907, in

the Klondyke with the Geological Survey of Canada; two years, 1910–1912, as the head of a geological expedition to the Belgian Congo; and from 1908 to 1914 as a member of the Geological Survey of Saxony. His earliest contributions were in the fields of ore deposits and petrography, and his doctor's dissertation on "The Geology and Origin of the Lapland Iron Ores" was



OTTO STUTZER

awarded the Carnegie Medal of the Iron and Steel Institute of London. His interest soon changed to the non-metallic deposits and as early as 1911 appeared the first volume of his "Nicht-Erze," an encyclopedic treatment of the non-metallic mineral deposits now comprising six volumes.

Equally brilliant was Dr. Stutzer's service as an officer during the World War, culminating as chief geologist on the Italian front and on the Somme.

After the World War, his geologic interests spread to the fuels, first to

coal and then to include petroleum. For six years, from 1920 to 1926, the field of his activities was transferred to Colombia where he was first chief geologist of the Sociedad Colombiana de Fomento and later chief of the Comision Cientifica Nacional. Though his work in Colombia was primarily as a petroleum geologist, his geologic contributions cover a wide range and are published in part in the "Compilacion de los Estudios geologicos oficiales en Colombia" and in the *Neues Jahrbuch* as "Beiträge zur Geologie und Mineralogie von Kolombien." As a by-product of his tropical experiences in Africa and South America, he wrote a booklet on "Tropisches Buschleben."

In 1927 he returned to Freiberg as professor of the newly established chair in the geology of fuels, which post he held until his death. During this period he made numerous contributions to the geology of coal and petroleum.

Dr. Stutzer's international fame is attested by his selection as umpire in the important Lena Goldfields case, and by his election to the presidency of the Society of Economic Geologists. When he arrived in New York in December, 1935, to present his presidential address on "Carbon Dioxide Eruptions from Coal Seams in Lower Silesia," though widely known by his work, only a few of the American geologists had had opportunity to know him personally. In his characteristically energetic way, he spent four months touring the United States, visiting seats of geologic learning and points of geologic interest, and making himself widely known personally to his American colleagues. Typical of the insatiable scientific appetite of the man is the following extract translated from a letter which he wrote aboard ship on his way home.

> In New York I found 46 boxes. In Germany I shall have to arrange the collections I made and assimilate the enormous accumulation of literature I gathered. This will take a long time. I hope to return in two or three years to make more detailed studies. This time it was more an information trip on which I saw much and learned much.

JOSEPH T. SINGEWALD, JR.

THE JOHNS HOPKINS UNIVERSITY
BALTIMORE, MARYLAND
November, 1936

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 21, NO. 1 (JANUARY, 1937), PP. 142-148

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

RUTHVEN PIKE, after several years in Argentina, spent a vacation in the United States, England, and on the Continent. His address is Iraq Petroleum Company, City Gate House, Finsbury Square, London.

S. W. LOWMAN was the speaker at the Houston Geological Society's meeting of October 8. He discussed the differences in the Mid-Continent and Gulf Coast subsurface laboratory methods.

C. H. RANKIN, formerly production foreman for the Continental Oil Company in the Jesse area, Oklahoma, has been made district superintendent of the Shiprock district in New Mexico, taking the place left vacant by the death of E. M. RAMSEY.

A. H. NOBLE has changed his address from Sarawak Oilfields Ltd., Miri, Sarawak, to De Bataafsche Petroleum Mij, The Hague, Holland.

E. F. BOEHMS, paleontologist, recently with University Lands at San Angelo, may now be addressed in care of the Forest Development Company, Abilene, Texas.

W. V. HOWARD, consulting geologist, Wright Building, Tulsa, addressed the Tulsa Geological Society, November 2, on "Oil and Gas Possibilities of Illinois and Southwest Indiana."

A. I. LEVORSEN, past-president of the Association, talked on "Time of Oil Accumulation" before the Kansas Geological Society at Wichita, October 27.

The new officers of the Shawnee, Oklahoma, Geological Society are: president, JACK M. COPASS, Amerada Petroleum Company; vice-president, DON L. HYATT, Carter Oil Company; and secretary-treasurer, M. C. ROBERTS The Texas Company.

Word has been received from the Venezuelan Geological Survey at Caracas that plans are materializing for the First Venezuelan Geological Congress to be held in February, 1937.

VINCENT W. VANDIVER is district geologist in the National Park Service, with headquarters at Santa Fe, New Mexico. For several months he has been working with HERBERT E. GREGORY in the southern part of the Colorado Plateau.

GLEN S. NORVILLE has resigned as division geologist of the Oklahoma division of the Continental Oil Company and has opened an office at 901 Colcord Building, Oklahoma City, for consulting work for several Oklahoma and Kansas operators.

SAM KORNFELD has opened an office at 415 Brown Building, Wichita, Kansas, for royalty investments and drilling propositions. He will continue editing the syndicated newspaper feature "Oil Oddities."

PHILIP S. SCHOENECK, district geologist for the San Antonio district of the Atlantic Refining Company, is now located at 1742 Milam Building, San Antonio, Texas. A. H. ALCORN, assistant geologist, has been transferred to the same offices.

MELVIN M. GARRETT, consulting geologist, 207–10 City National Bank Building, Wichita Falls, Texas, has opened offices at 411 Republic Bank Building, Dallas.

J. BRIAN EBY, geophysicist, was guest speaker at Houston University's course on petroleum, October 29, his subject being "Geophysical Methods for Finding Oil."

BOUWE DYKSTRA, formerly Texas Panhandle division manager of the Shell Petroleum Corporation, has been made chief exploitation engineer with headquarters in Tulsa.

CARL MELZER addressed the Rocky Mountain Association of Petroleum Geologists at Denver on November 2, his subject being "A Trip Along the Continental Divide from Wyoming to New Mexico."

G. ODWIN CATE, of the geophysical department of the Humble Oil and Refining Company, has been transferred from Midland to Gainesville, Texas.

JAMES P. FOX has changed his address from San Antonio, Texas, to the production department, Standard Oil Company of California, 225 Bush Street, San Francisco, California.

J. LAWRENCE MUIR of the Amerada Petroleum Corporation has been transferred from Enid to Shawnee, Oklahoma. His address is 315 W. Independence, Box 744.

S. H. WILLISTON, geologist for the Sun Oil Company, has his headquarters in the Public Service Building, Portland, Oregon.

ARTHUR H. PETSCH is now in charge of the Ohio Oil Company's recently opened office in Laredo, Texas.

HARRY R. JOHNSON, consulting geologist, was elected president of the Pacific Section of the American Association of Petroleum Geologists at the section's 13th annual meeting. JAMES C. KIMBLE, geologist with General Petroleum Corporation, Los Angeles, was elected secretary-treasurer.

E. D. WINGFIELD, of the Freeport Sulphur Company, was the speaker at the meeting of the Houston Geological Society, November 5. He discussed the mining of sulphur in the Gulf Coast Region.

PAUL D. CRAWFORD was speaker at the meeting of the Houston Geological Society, November 12. He discussed field technique of the magnetometer and its uses in locating serpentine plugs.

The Shreveport Geological Society, at its November meeting, elected SHAPLEIGH GRAY of The Texas Company, president; H. K. SHEARER of the Hunter Company, Inc., vice-president; and C. R. MCKNIGHT of the Arkansas Fuel Oil Company, secretary-treasurer. M. C. ISRAELSKY was guest speaker at the meeting. The Society meets on the first Friday of every month in the Civil Courts Room, Caddo Parish Court House. The luncheon is on every Friday noon at the Caddo Hotel, Shreveport, Louisiana.

M. M. KORNFELD, consulting micro-paleontologist and subsurface geologist, is now located at the Second National Bank Building, Houston, Texas.

DORSEY HAGER opened an office in the Esperson Building, Houston, on December 1. He will still maintain his offices in Winnipeg, Manitoba, and Lansing, Michigan.

VIRGIL R. D. KIRKHAM, economic geologist of Saginaw, Michigan, spoke on "Conservation and Stabilization Synonymous in the Petroleum Industry" at the annual meeting of the Independent Petroleum Association of America in Oklahoma City.

C. E. DECKER, of the University of Oklahoma, directed a tour of geologists from Oklahoma City and near-by cities, November 21, over the Arbuckle uplift. The trip was sponsored by the Oklahoma City Geological Society. R. W. HARRIS made a talk on micropaleontology principally of the Simpson formation, and described and exhibited some new micro forms.

J. V. HOWELL, consulting geologist, spoke before the Tulsa Geological Society, November 16, on "Geologic Notes of Northwest Canada."

HARVE LOOMIS, consulting geologist, Abilene, Texas, addressed the Fort Worth Geological Society, November 5, on geological features of the East Indies.

FRED S. WRIGHT, formerly district geologist for The California Company in West Texas, has opened offices with J. W. McMillen, independent producer of Ponca City, Oklahoma, at Midland, Texas.

ROBERT M. WHITESIDE, geologist of Tulsa, died in Dallas, Texas, November 19.

THURMAN H. MYERS has resigned from The Penn-United Gas Company, Wellsboro, Pennsylvania, and is now employed as chief engineer and geologist, and head of the land department of The Carnegie Natural Gas Company, 1014 Frick Building, Pittsburgh, Pennsylvania. His home address is 1541 Grandin Avenue, Dormont, Pennsylvania.

T. A. HENDRICKS, of the United States Geological Survey, presented a paper on "Geology of McAlester and Black Knolls," at a recent meeting of the Shawnee Geological Society.

At the second midyear meeting of the Society of Petroleum Geophysicists, held in Houston, November 20–21, the following papers were presented: "Exploration of the Reflection Seismography in the Gulf Coast," by E. E. ROSAIRE, president; "Gravitational Survey with the Gravity Meter," by L. M. MOTT-SMITH; "The Effect of Moisture on the D.C. Resistivity of Oil

Sands," by J. J. JAKOSKY and R. H. HOPPE; "Abnormal Velocities in Sedimentary Beds in Western Utah," by A. L. SMITH; "Some Gulf Coast Velocity Curves," by C. M. BOOS; "Geologic Discussion of the Gulf Coast," by F. W. ROLSHAUSEN; "Psychology and Geophysical Exploration in the Gulf Coast," by E. E. ROSAIRE and K. RANSONE; "Complex Reflection Patterns and Their Geologic Sources," by FRANK RIEBER; "Keeping Cost Records on Insurance," by A. C. BURNETT; "Recent Developments in Explosives for Seismograph Exploration," and "Developments of Essential Characteristics of Electric Blasting Caps for Seismograph Prospecting," by W. FARREN, GUY ROLAND, and HAROLD WHITE; "Let the Physicists Change Your Oil," by PAUL D. FOOTE; "Electro-Chemical Exploration and Correlation of Cased Bore-Holes," by M. C. BOWSKY; "Field Technique of the Magnetometer and Its Uses in Locating Serpentine Plugs," by PAUL D. CRAWFORD; "Notes on Dip Shooting," by SYLVAIN PIRSON.

RICHARD T. LYONS, formerly vice-president in charge of land and geological departments of the Skelly Oil Company in Tulsa, has resigned to become head of the land and geological departments of the Tide Water Associated Oil Company, Houston, Texas.

J. M. NISBET, formerly manager of the land and geological division of the Empire Oil and Refining Company, resigned January 1. He plans to locate in Upland, California, where he will devote his time to his personal interests.

R. H. DURWOOD, resigned from the geological department of the Plymouth Oil Company, San Antonio and Sinton, to enter the consulting field as geologist and magnetometer operator.

The Ardmore Geological Society had a two-day trip to study the Pennsylvanian section of north-central Texas, December 4–6. M. G. CHENEY and F. B. PLUMMER conducted the trip.

ALEX W. MCCOY, geologist, spoke at the first public meeting of the 1936–1937 season of the Tulsa chapter of the American Petroleum Institute, December 9, on "The Next Five Years in Oil."

GUY E. GREEN, of the geological department of the Wellington Oil Company and Santa Clara Oil Company in San Antonio, has been elected to the board of directors of that concern and will be actively in charge of part of the company's business as vice-president.

PAUL WEAVER, geologist for the Gulf Oil Corporation, Houston, addressed the Shreveport Geological Society, December 4, on "Heaving Shale Encountered in Drilling on Salt Domes on the Gulf Coast."

RICHARD J. RUSSELL of Louisiana State University, Baton Rouge, recently addressed the Shreveport Geological Society, on "Some Notes on the Geosynclinal Theory."

STUART MOSSOM, formerly of the geological department of the Magnolia Petroleum Company, in San Antonio, has been made San Antonio district geologist for the company, with headquarters at 1704 Alamo National Building.

M. M. KORNFELD discussed microscopic methods in localized subsurface geology at the meeting of the Houston Geological Society, December 3.

CHARLES B. CARPENTER, petroleum engineer for the United States Bureau of Mines, was elected president of the Dallas Petroleum Geologists. DILWORTH S. HAGER, geologist and producer, and R. A. STEHR, geologist for the Seaboard Oil Corporation, were elected vice-president and secretary-treasurer, respectively.

J. A. BARNETT has resigned from the petroleum engineering department of The Texas Company at Houston and has accepted appointment with the oil and gas operations branch of the United States Geological Survey for petroleum engineering work in New Mexico with headquarters at Roswell.

TED SHELTON, formerly with William H. Atkinson of Oklahoma City, is now in the employ of the Wilcox Oil and Gas Company with headquarters at Tulsa.

FRANK RINKER CLARK, vice-president of The Ohio Oil Company, and Natalie Carter Broach, of Tulsa, Oklahoma, were married on November 28, 1936.

The Dow Chemical (see advertising page viii) has announced the opening of a Chicago office in the Field Building, 135 South La Salle Street, with Wilson I. Doan in charge, assisted by K. M. Wildes.

LOUIS ROARK has moved his office to the sixth floor of the Oklahoma Natural Gas Building, corner of Seventh and Boston, Tulsa, Oklahoma.

The New Mexico Geological Society arranged various field trips to study the Permian sections west of Carlsbad on November 14 and 15, following a trip through the potash mines.

H. ROGERS VAN GILDER, formerly with the Pennsylvania Power and Light Company, is associated with the partnership of Shoop and Stocum, oil and gas operators of Olean, New York.

Judge PAUL J. MCCORMICK in the District Court of the United States for the Southern District of California, Central Division, on October 21, 1936, ruled that Patent No. 1,770,224 for borehole directional apparatus and method of orientation, held by Alexander Anderson, Inc., was a pioneer and generic invention. This was in a suit known as No. Equity 735-M (consolidated cause), filed by Alexander Anderson, Inc., against Eastman Oil Well Survey Company of California, Eastman Oil Tool Company, Eastman Instrument Company, and H. John Eastman. The decree enjoins the defendants from further infringement and orders an accounting.

JAMES W. KISLING who has served as district geologist for the Amerada in Tyler for a number of years, has been transferred to the Houston office of his company, where he will replace LEWIS W. MACNAUGHTON who has resigned. S. R. SELF has been transferred to the Tyler office from Midland, Texas.

A. C. WRIGHT has been transferred from the Shreveport office of the Shell Petroleum Company to Tyler, Texas, and will act as district geologist in their office recently opened.

In the latter part of 1936, the following short talks were given at the Monday luncheons of the Fort Worth Geological Society: WADE H. HADLEY, "Geology of North Carolina"; S. M. GREENIDGE, "Oil Taxation"; JOHN F. HOSTERMAN, "Monument Field in New Mexico"; ROBERT D. SPRAGUE, "Stratigraphy of East Texas and Northwestern Louisiana"; and GEORGES VORBE, "Geology of the Grand Canyon." On Friday evening, November 5, HARVE LOOMIS, of Abilene, delivered an illustrated lecture on "Java" before the Society, their wives and friends, at the Brite Chapel at Texas Christian University.

P. E. FITZGERALD, of Dowell, Inc., addressed the University of Tulsa Student Chapter of the American Institute of Mining and Metallurgical Engineers, December 10, on "Acidizing of Oil and Gas Wells."

GLENN D. HAWKINS has opened an office as consulting geologist at 734 Kennedy Building, Tulsa.

The United States Geological Survey announced in the January, 1936, number of the *Bulletin* that the final colored edition of the geologic map of Texas probably would be issued late in 1936. The engraving has progressed as rapidly as possible, but it now appears that the final map can not be ready for distribution before late in the spring of 1937. The date of issue and the price of the new map will be announced in this *Bulletin* as soon as they are determined.

ALLAN M. SHORT is employed by the Stanolind Oil and Gas Company at Shawnee, Oklahoma.

J. MARVIN WELLER, geologist and head of the division of paleontology and stratigraphy, Illinois Geological Survey, has been teaching the courses in petroleum geology during the illness of FRANK W. DEWOLF, head of the department of geology and geography, University of Illinois.

E. W. BRUCKS has accepted a position with the Continental Oil Company of Delaware for work in the Houston, Texas, district.

The Rocky Mountain Association of Petroleum Geologists offered the following programs recently: at Boulder, HARRY MACGINITIE, "Geologic Climates, Theories Old and New"; at Denver, D. P. BARNES, "Soil and Ground Water Problems Encountered in Dam Construction."

T. A. HENDRICKS addressed the Tulsa Geological Society, December 7, on "Stratigraphy of Pre-Pennsylvanian of Black Knob Ridge of Southeastern Oklahoma."

JOSEPH H. TURNER, for the past 6 years chief geologist for the Pennsylvania Power and Light Company, with headquarters in Wellsboro, Pennsylvania, has resigned from that company, effective January 1, 1937. He will be located in the Alamo National Bank Building, San Antonio, Texas.

CHESTER D. WHORTON is now associated with Godfrey L. Cabot, Inc., of Boston, Massachusetts, with headquarters in Olean, New York.

The Appalachian Geological Society, at its meeting, December 14, elected the following officers: president, J. E. BILLINGSLEY, Commonwealth Gas

Corporation, Charleston, West Virginia; vice-president, I. B. BROWNING, consulting geologist and producer, Second National Bank Building, Ashland, Kentucky; secretary-treasurer, CHARLES BREWER, JR., Godfrey L. Cabot, Inc., Box 348, Charleston, West Virginia.

MAURICE EWING is now head of the scientific staff on a submarine which is determining the values of gravity at sea in West Indian waters. The submarine left Coco Solo, Panama Canal Zone, on November 30 and was to reach Trinidad on December 4.

J. W. BRICE, chief geologist of the Standard Oil Company of Venezuela, is at Caripito, Venezuela, after being in the United States last fall.

H. W. STRALEY, III, of the geophysical laboratory of the University of North Carolina, spoke before the Mineral Club of the Virginia Polytechnic Institute, November 19, on "Geophysical Prospecting."

The San Antonio Geological Society held its New Year's Frolic at the Plaza Hotel, San Antonio, Texas, December 31. W. W. MCDONALD was chairman of the arrangements committee.

J. L. KALB, chief geologist of the Lago Petroleum Corporation, Maracaibo, Venezuela, is spending several months in the United States.

R. L. CANNON, JOHN EMERY ADAMS, E. RUSSELL LLOYD, and others discussed the origin of oil before the West Texas Geological Society, at Midland, Texas, December 19.

The annual Christmas party of the Midland Geological Society was held at the Scharbaner Hotel, Midland, Texas, December 23.

A. I. LEVORSEN, consulting geologist of Tulsa, Oklahoma, and past-president of the Association, gave a series of four lectures at the University of Kansas, December 14–17. The titles of the talks were: "Miscellaneous Problems in Petroleum Geology," "Paleogeology," "The Accumulation of Oil," and "Petroleum Reserves and Discovery."

E. T. BENSON, of the Shell Petroleum Corporation, talked on "Studies in Cyclic Sedimentation in the Pennsylvanian," before the Tulsa Geological Society, December 21.

W. S. LEVINGS was the speaker at the meeting of the Rocky Mountain Association of Petroleum Geologists, December 21, in Denver, Colorado, His subject was "Petroleum Prospecting in Angola, West Africa."

The Oklahoma Geological Survey, ROBERT H. DOTT, director, at Norman, has completed a mineral survey of the state and the following special studies: geology of Muskogee-Porum district by C. W. WILSON, Jr., with a chapter on Pennsylvanian stratigraphy by NORMAN D. NEWELL; Oologah limestone near Tulsa, by C. T. KIRK and H. B. GOODRICH; Simpson in Criner Hills and Arbuckle Mountains, and Arbuckle in Arbuckle and Wichita mountains, by C. E. DECKER; surface rocks of northwestern Cimarron County, by J. W. STOVALL; Eleventh Street limestone near Tulsa, by A. N. MURRAY; older rocks of northeastern Oklahoma, by SAMUEL WEIDMAN; and Tertiary sands near Norman, by A. J. WILLIAMS.

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Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

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Meetings: Second Friday, each month, at 6:30 P.M.
Luncheons: Fourth Friday, each month, at 12:15 P.M.
Place: Hamilton Building

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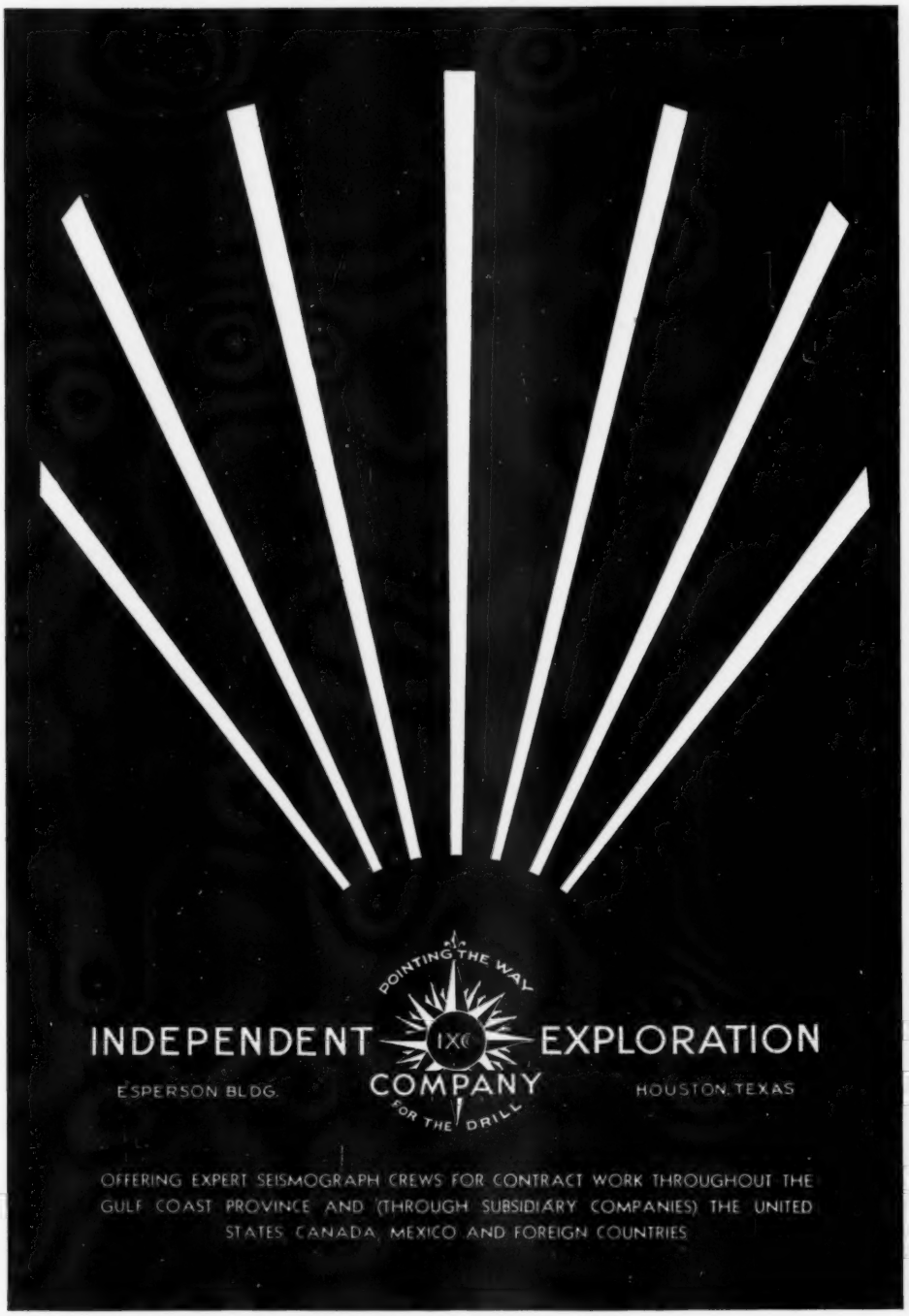
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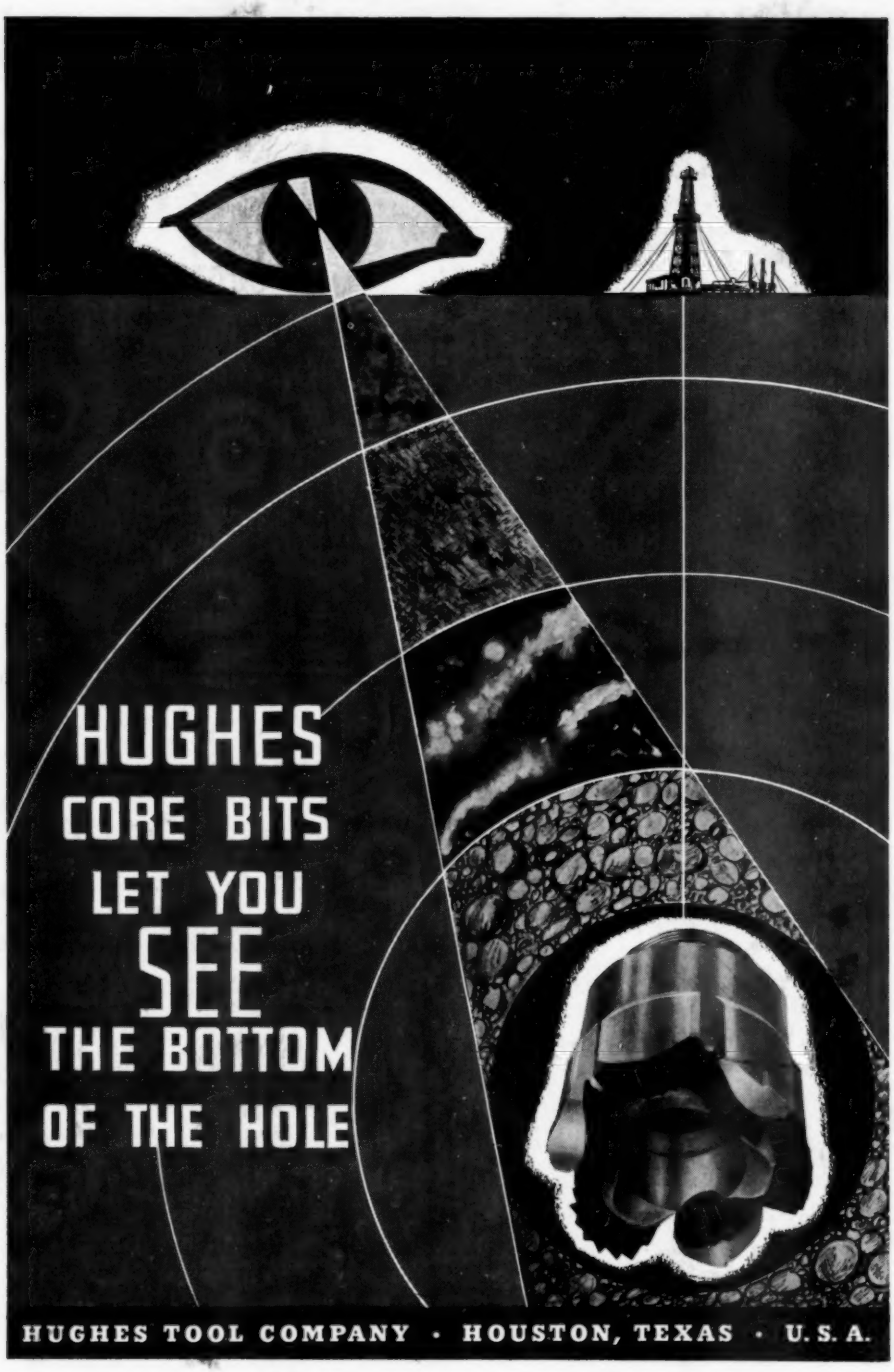
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